NUCLEONICS

Special clays→
may solve waste
disposal problem
page 14

Consolidated Engineering Leak Detector, Model 24-101A (above) is a simplified mass spectrometer sensitive to minute traces of helium. It can be used with either the probe or envelope method. The self-contained unit includes mechanical and diffusion pump; and all necessary controls and instruments.

CVC Leak Detector, Model LD-01 (above right) uses a sensitive element containing a heated platinum anode and cold cathode with relatively low voltage between them. The circuit uses standard radio tubes, operates on 115-volt ac current.

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DECEMBER • 1954

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This task force at Solar's Des Moines plant is studying a complex diffuser assembly, on which Solar is working both in stainless steel and titanium. Clockwise are Charlie Ragan, assistant contracts manager; Bill Dixon, chief production engineer; Bob Ballard, manager of manufacturing; Ed Gunton, assistant plant manager—operations; Bill Schilling, chief design engineer, and Hi Brown, chief metallurgist.

A Solar Task Force can help you solve special problems

IN EVERY NEW SOLAR PROJECT, the first step is the formation of a project task force. The requirements of the new job are studied and the engineering and shop skills demanded by it are noted. Next, individual engineers and specialists in these fields are selected from Solar's many departments, from research through production.

These men, as a team, are charged with full responsibility for the successful completion of their project. Each task force team is free to call for additional specialists whenever they are needed.

Through this task force system, each project – large or small – benefits from *all* of Solar's knowledge and 27 years' experience in designing and building heat resistant alloy products. The task force system has resulted in many important design improvements, as well as impressive savings in production costs.

Solar will be happy to assign a task force team to help *you* solve special problems.

SOLAR AIRCRAFT COMPANY — SAN DIEGO, DES MOINES

DESIGNERS, DEVELOPERS AND MANUFACTURERS OF METAL ALLOY PRODUCTS

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Solar specializes in the manufacture of precision products from alloys and special metals for severe service. Solar's experience since 1927 is unduplicated in this field. Solar skills and facilities range from research, design and development through to mass production. Wherever heat, corrosion or difficult specifications are problems, Solar can help you solve them.

PLANTS. *In San Diego and Des Moines (photograph above). A total of 1,400,000 sq ft of floor space. Approximately 5,000 employees. Annual sales over $65,000,000.*

EQUIPMENT. *Production equipment for all types of metal fabrication —forming, machining, welding, brazing, casting, coating. Extensive laboratory and testing equipment. Facilities for development, prototype, limited or mass production.*

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Current orders include aircraft engine and airframe parts, alloy castings, pneumatic ducting, atomic energy components. Customers include some of the most honored names among aircraft and industrial companies in the U.S. and Europe.

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Bellows. *"Sola-Flex"® bellows and expansion joints in many designs from ½ in. up to the world's largest, 28 ft in diameter.*

Gas Turbines. *Solar "Mars" 50 hp engines for auxiliary generator sets, ground carts, portable fire pumps; Solar "Jupiter" 500 hp engines in variable and constant speed models.*

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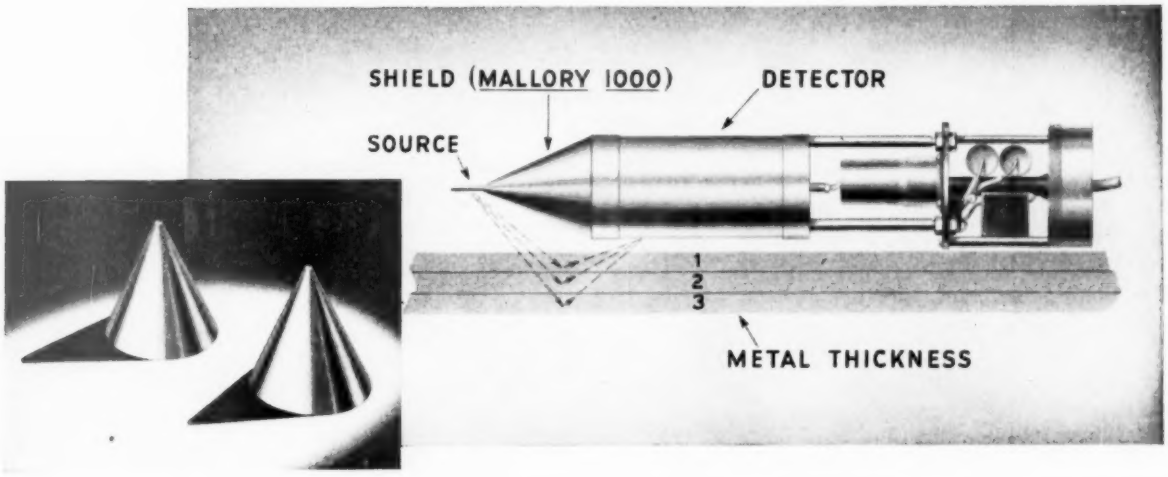
Only MALLORY 1000 METAL

Could Effectively Handle this Radiation Shielding Job



This MALLORY 1000 METAL cone is used in the nose of an instrument called the Penetron®, made by United Engineers, Inc. of Tulsa, Oklahoma. It measures wall thicknesses of closed vessels and pipes without taking them out of service.

A gamma ray source in the head of the Penetron emanates rays which pass through the material being measured. A detector, effectively shielded from the primary source by MALLORY 1000 METAL, picks up secondary gamma ray emission from the material and measures the thickness.

By using MALLORY 1000 METAL, the manufacturer of the Penetron gained these important advantages:

- Effective shielding because of high density —16.96 grams per cubic centimeter.
- Easy fabrication to desired shape because of excellent machining characteristics.
- High dimensional stability not obtainable in lead. Tensile strength of MALLORY 1000 is 105,000 lb. per square inch.
- Total size and weight of the detector was reduced.

For *any* shielding application, be sure you have all the facts about MALLORY 1000 METAL. A Technical Bulletin is yours for the asking.

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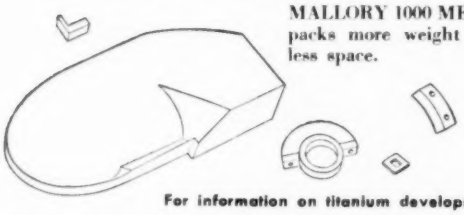
MALLORY

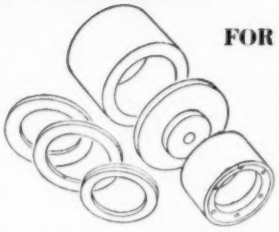
P. R. MALLORY & CO., Inc., INDIANAPOLIS 6, INDIANA

FOR COUNTERWEIGHTS . . .



MALLORY 1000 METAL packs more weight into less space.

FOR ROTORS . . .



MALLORY 1000 METAL has no objectionable drift at rotational speeds as high as 40,000 rpm.

For information on titanium developments, contact Mallory-Sharon Titanium Corp., Niles, Ohio

G.E. Designs New Alpha Particle Detector for Health Monitoring Against Radiation

General Electric's new alpha particle detector is a dependable monitor for inspecting clothing, machinery, laboratory areas or equipment suspected of containing alpha radiation.

EASY TO USE, the detector weighs less than 2½ pounds, including 10 feet of cable and connectors. It has an exceptionally large detection area of 150 square centimeters; is capable of detecting alpha particles having energies as low as two mev.

COMPACT CONSTRUCTION consists of a zinc-sulphide phosphor, photomultiplier tube and cathode follower pre-amplifier giving 0.25 volt output pulses. These pulses are transmitted to a scaler or rate meter. The detector also makes a rapid and sensitive survey meter when connected with a simple audio-speaker, which produces an audio "popping" noise.

PRICE is $249.60* and the detector is available from stock. For further information contact nearest G-E Apparatus Sales Office, or write for Bulletin GEA-6117, Section 605-81, General Electric, Schenectady 5, N.Y.

*Manufacturer's suggested retail price

Progress Is Our Most Important Product

GENERAL ELECTRIC

LATE NEWS and COMMENTARY

International Plans

Behind-the-scenes planning for implementation of proposed international atomic energy activities (see p. 70 for earlier details) is well under way. It is expected that an international agency will be set up by mid-'55. Bilateral negotiations between the U. S. and other nations are now in progress, with Morehead Patterson in charge for the U. S.

The second phase of the international program—a world technical nuclear conference to be sponsored by the UN—is also shaping up. Primary responsibility for it will be handled by a committee of the UN secretariat under Ralph Bunche. Detailed planning of the technical program will be by a seven-nation advisory committee. Presumably the committee will consist of those principal scientists in each country that have been advising their respective UN delegations on atomic energy—I. I. Rabi, U. S.; Sir John Cockcroft, U. K.; W. B. Lewis, Canada; F. Perrin, France; H. J. Bhabha, India; and Admiral Alvaro Alberto, Brazil. It is not known who the Russian representative will be. Announcement of his name may provide the first indication of who Russia's principal scientist in this field is. Rabi, chairman of the U. S. AEC's General Advisory Committee, is being assisted by Robert Charpie of Oak Ridge National Laboratory.

It is now expected that the conference will be held the first two weeks of August, 1955, in Geneva. It will probably have a semiofficial status and be a limited invitation affair. Foreign scientists are anxious that this be a high-technical-level meeting. Many of them feel that insufficient information was declassified for the Ann Arbor nuclear engineering congress last June and that it is necessary to declassify much more to make the coming meeting worthwhile. Unless this is done, they feel, the meeting may be a diplomatic boomerang for the U. S. (It is of interest to note with respect to declassification matters that two European journals recently published U^{235} cross section data that is reportedly classified in this country.)

Apparently Americans below the policy level responsible for suggesting technical subjects for the conference agree with the foreign sentiment on declassification. The program being proposed to the U. S. AEC by these Americans covers every conceivable phase of reactor technology and would require a major policy decision on declassification. The suggested program calls for double sessions, six hours a day, for two weeks. Evening sessions may also be held with distinguished scientists discussing broad fields of interest.

•

Hafstad Resignation

Announcement last month of the resignation of L. R. Hafstad, director of AEC's division of reactor development, has caused much speculation on the effect that a change in this post will have on industrial activity. Up in the air at the moment are many decisions affecting industry (regulations under the new law, prices AEC will charge for leasing nuclear fuel and will pay for regenerated fuel, joint AEC-industry reactor ventures, etc.). The man that takes Hafstad's spot could have considerable influence on such matters.

One man reported as being considered for the job is Alvin C. Graves of Los Alamos Scientific Laboratory. Graves, a physicist from the University of Chicago, has had principal scientific responsibility for many U. S. weapons tests.

Hafstad, AEC's first and only reactor chief, will go to Chase National Bank on Jan. 1 as atomic energy consultant. He will represent Chase in conferring with groups planning industrial atomic developments. Chase is one of the principal banking institutions involved in utility financing.

LATE NEWS (Continued)

Progress on Regulations AEC hopes to have much of its preliminary planning on implementation of the new law completed in time for the hearings to be held by the Joint Committee on Atomic Energy during the first 60 days of the next Congress. The hearings are designed to give Congress a regular look at how the law is functioning.

•

Army Reactor Eighteen of the 33 companies invited to submit bids on the Army Package Power Reactor actually came through by the November 19 deadline. The contract award is expected to be made by the first of the year. Although some companies did not specify who they would buy their fuel elements from if they got the bid, it is significant that at least three manufacturers have indicated willingness to guarantee performance of the elements. On the total bid prices submitted, AEC reportedly is pleased with the price spread (presumably small).

•

Argonne Reactor Argonne National Laboratory's new research reactor, CP-5, is now an "open-access" facility. AEC has removed security restrictions affecting reactor access.

•

New York Reactor? Consolidated Edison Co. of N. Y. may build a nuclear power plant on a 300-acre site at Indian Point Park on the Hudson River. Recently acquired, "the suitability of the site for an atomic power plant is under study," according to the company. It is reportedly expecting to go to AEC shortly with a letter of intent. The company does not plan to join with other utilities in the project, nor will it seek government financial support. Edison is interested in a power-only reactor and feels it is not important for them to get a price for regenerated fissionable material based on its military value. The company has been "talking to manufacturers who say they can build us a plant." Vitro Corp. has been hired as consultants to evaluate such proposals.

•

Why Cosmotron Failed After exit quadrant of Brookhaven National Laboratory's Cosmotron magnet shorted out on November 5, speculation attributed failure to radiation breakdown of insulation, reduction of insulation ionization potential, or metal chips in insulation. But when workers removed concrete shield and copper-bar sections of magnet, they found that water had leaked from end of water-cooled copper bar, seeped between bar and insulation for about 4 ft, and then caused short. Preliminary estimate of repair time is 3 to 4 months—including some improvements previously stalled by pressing experiments. Vacuum chamber is being modified to allow intense proton beam to emerge; new low-level r-f system is being installed and entire r-f system studied; concrete shield is being modified to allow better experimental setup.

•

LMFR Contract The liquid metals fuel reactor (LMFR) proposed by Brookhaven (NU, July '54, p. 11) is being evaluated for AEC by the following organizations working under Babcock and Wilcox: American Smelting and Refining, Union Carbide, Oak Ridge National Laboratory, Vanadium Corp., Air Reduction, Giffels and Vallet, Dow Chemical, TVA, Bechtel (representing Nuclear Power Group) and possibly International Nickel. Fifteen men are to work on the project at Brookhaven, aiming at a June '55 completion date.

•

Libby Confirmed The appointment of Dr. W. F. Libby, named to the AEC on Sept. 13 by President Eisenhower, was confirmed by the Senate on Dec. 2 after Senator Estes Kefauver reversed his decision to block the appointment.

NUCLEONICS DECEMBER, 1954

Jerome D. Luntz, *Editor*

Building the International Atom

FOR THE FIRST TIME since the scientific world instituted self-censorship in atomic energy in 1939, important steps are being taken to renew worldwide cooperation in this field. As reported in detail on p. 70, the United States has proposed United Nations support for peacetime atomic energy activities and has also outlined a U. S. plan for immediate help to various nations.

It was in 1939 that foreign scientists told Americans about important European developments in the field of fission. This led to the highly secret U.S.-U.K.-Canadian effort to build the atomic bomb. It wasn't until well after World War II that other countries began to work in atomic energy. Many now have vigorous programs, but others are lagging because of lack of fissionable material and/or knowhow.

Although the full scope of the proposed international effort is not yet clear, it is apparent that dissemination of information will be a major activity. A vast body of technical data on nuclear reactors and radioisotopes already exists in the nonsecret literature. But much still remains concealed, particularly on power reactors.

IN ANTICIPATION of increased international cooperation, the U. S. Congress passed the Atomic Energy Act of 1954, which permits, for the first time, communication by the U. S. to other nations of "restricted data" on "refining, purification and subsequent treatment of source material; reactor development; production of special nuclear material; health and safety; and other applications of atomic energy for peaceful purposes." It will be possible, via bilateral agreements, for this country to reveal sensitive and nonsensitive classified data in these subject areas.

But the information will be classified. This could lead to trouble. A very significant statement on this was recently made by Gordon Dean, former chairman of the Atomic Energy Commission. He said:

"Foreign countries that wish reactor information, presently classified, will have to set up security standards similar to this country. This is completely unrealistic and we may very well tie our hands and make a few enemies rather than friends . . . I am sure it will be completely unworkable if we try to police the security systems of all the countries with which we deal . . .

"The only reason we have a security system is that we do not want to add to the Russian stockpile. Another fact is that the Russians have a stockpile, a sizeable one; and within a matter of a few years will have enough of a stockpile to cancel out, for all practical purposes, the much larger U. S. stockpile. Since it would take the Russians about three years to take the latest reactor information and with it build a modern reactor; and since perhaps the most they could expect to add to their stockpile because of it would be a small increase in the amount of plutonium manufactured; and since this would be but a drop in the bucket compared to what they have already produced, and could have no effect on 'the cancelling out' situation, I submit that if we operate on the assumption that there are real security considerations in the reactor field we are going to tie our hands and the hands of other countries of the West."

ALTHOUGH UNCLASSIFIED INFORMATION is widely available, it can frequently be difficult to locate, particularly for the uninitiated. Because of this, the Editors of NUCLEONICS repeat an offer that they made in 1951—to assist any reader, especially those in foreign countries, in getting nonsecret information in the atomic energy field. We shall be particularly happy to help those just starting to work in atomic energy by advising on availability and sources of information.

We feel it is most appropriate for this journal to make such an offer because NUCLEONICS is an international journal in the fullest sense of the word. In addition to having published articles from more than a dozen countries, NUCLEONICS now has subscribers in 64 nations. Of our more than 11,000 circulation, about 2,200 is foreign. We have 345 subscribers in 11 countries in South America; 106 in Central America; 334 in Canada; 1,033 in 19 countries in Europe; 209 in 17 countries in Asia; 37 in 8 countries in Africa; and 61 in Australia.

It is only through cooperative efforts that atomic energy can be put to use around the world. We hope that the international program gets under way and that NUCLEONICS can contribute to its growth.

Administrative Problems in

RADIATION PROTECTION

By IRVING R. TABERSHAW
and SAUL J. HARRIS
Director and Associate Radiophysicist
Division of Industrial Hygiene
New York State Labor Department
New York, New York

In the light of new legislation and wider application of radiation, public welfare requires close scrutiny of health and safety regulations on Federal, state, local, and industry levels. After analyzing existing codes, the authors suggest items essential to formulation of effective radiation-protection codes

THE NEW ATOMIC ENERGY ACT encourages rapid expansion of industrial and medical applications of nuclear energy and radioisotopes. But the rapidity will in great measure be influenced by the legal and administrative climate provided by radiological health regulations at many levels.

The importance of health and safety is emphasized time and again in the Act itself; the need for protection against possible damage is what puts operation of nuclear installations into the "interstate commerce" category and thus under Federal regulation. In providing for licensing of nuclear and isotopic materials, the Act specifies that safety standards "to protect health and to minimize danger to life and property" must be set up by the Atomic Energy Commission and complied with by licensees. The Act even goes so far as to provide for license revocation for failure to comply with AEC regulations.

AEC regulations have not been completed; even when they are, the responsibilities of state, local, and other authorities will not be spelled out by them. All levels of government may have considerable say about reactor-building construction, zoning laws, operating taxes and fees, licensing of operators, and use and disposal of by-product materials.

In New York, the State Department of Labor has developed a radiation-protection code to the point where it may be put in effect in the near future. This article presents the philosophy forming the basis for this code and shows how this philosophy evolved. Included is an analysis of Federal, state, local and other regulations carried out in developing the New York code.

Interest in governmental regulation of radiation hazards was delayed until comparatively recent years by several factors:

1. X-ray and radium sources have been expensive to produce and thus did not find wide application until recently.

2. The few scientists working with radiation in isolated laboratories recognized the hazards and evolved standards of self-protection; they did not advise legislative protection.

3. Knowledge regarding detection methods and biological effects of radiation was lacking; since these effects are notoriously slow and not perceptible to human senses, neither physicians nor physicists were unduly alarmed.

Although there was no general demand for governmental regulation, scientific committees have worked actively on development of basic protection data since 1922. Health-physics research expanded sharply in 1942 with wartime atomic energy activity, but national security needs kept this information to a relatively small group.

When AEC began distributing radioisotopes after the war, it included health-safety provisions in regulations covering their use. But compliance has been achieved primarily through self-regulation. The current expansion in radiation usage, with possible effects on a larger segment of the populace, makes self-regulatory measures inadequate; prevention of radiation effects is an urgent governmental function. But regulations must be uniformly and equitably applied, for radiation protection is expensive and unfair competitive advantage may be obtained commercially while jeopardizing the health and safety of employees and the public.

Type of Regulatory Code

The unique characteristics of radiation affect the approach and scope of any regulatory code. Two approaches are possible—"specification" and "performance" codes.

A specification code details safeguards for each specific source and application; it permits enforcement more easily in a particular instance but is impractical as it lacks flexibility and retards development. A performance code, setting general exposure standards regardless of source or use, seems the only feasible approach to radiation control. This is made evident by con-

ANALYSIS OF 46 GOVERNMENTAL, INDUSTRIAL, AND OTHER RADIATION REGULATIONS*

	Date	Purpose stated	Items expressly prohibited	Specification / approach / Performance	Numerical exposure limit	Technical / definitions / Legal	License or permit required	Warning of radiation presence	Specific exemptions	Source classification by degree of hazard	Engineering controls required	Safe practice, instrumentation prescribed	Medical controls specified	Records required	"Expert" required	References included
Federal Agency Regulations																
Post Office	1949	X	X		X	X				X	X					X
I.C.C.	1948	X	X		X	X				X	X	X					X	
C.A.B.	1949	X	X		X	X		X		X	X	X					X	X
Fair Labor Standards Act	–	X	X		X													
A.E.C.	1951	X	X		X		X	X	X	X	X	X			X	X	X	
Military-Air Force	1951	X			X	X	X			X	X	X	X	X	X	X	X	X
National Bureau of Standards Handbook																
27—"Radio-luminous Comp"	1941	X		X		X				X			X	X	X		X	
38—"Radium During Air Raid"	1942	X		X						X			X	X			X	X
41—"Med. X-ray to 2 MeV"	1949	X		X		X	X	X		X			X	X	X	X	X	X
42—"Radioisotope Handling"	1949	X			X	X				X		X		X			X	X
47—"International Comm."	1951	X			X	X	X										X	X
48—"Lab. Contamination"	1951	X	X		X					X			X	X	X	X	X	X
49—"Med. Waste Disposal"	1951	X		X		X				X				X				
50—"X-ray Protection Design"	1952	X		X		X				X			X				X	X
51—"Methods & Instruments"	1952	X			X		X	X		X				X		X	X	
52—"M.P.C. in Air & Water"	1953	X			X	X											X	X
53—"C-14 Waste Disposal"	1953	X		X		X								X			X	X
54—"Protection Against Radiations from Ra, Co-60, and Cs-137"	1954	X		X		X	X			X			X	X	X		X	
56—"Cadaver & Isotopes"	1953	X			X	X				X				X				X
Municipal Regulations																
N. Y. City San. Code	1948	X	X	X		X			X	X				X			X	
Milwaukee Ordnance	–		X	X		X			X	X				X			X	
Cleveland (Recommend.)	–			X		X				X				X			X	
Detroit (Info. Sheet)	–			X		X				X					X	X	X	
Louisville, Ky.	–		X	X		X			X	X				X			X	
Newark, N. J. (proposed)	–	X			X	X	X	X	X	X				X	X	X	X	X
State Regulations																		
Kentucky (proposed)	–		X	X		X			X	X				X			X	
Indiana	–			X		X			X	X				X			X	
Mississippi	–			X		X			X	X				X			X	
West Virginia	–			X		X				X				X			X	
Michigan (Recommend.)	–			X		X				X				X			X	
Texas (Info. sheet)	–			X		X			X	X				X			X	
Connecticut Health Dept.	1952	X		X		X	X	X	X	X				X			X	
New Jersey Health Dept.	1952	X		X		X	X	X		X				X			X	
New York Health Dept.	1953			X						X				X				
Massachusetts (Info. sheet)	1951	X	X		X	X				X				X				
Penn. Labor (proposed)	–	X			X	X	X	X	X	X		X	X	X	X	X	X	X
Calif. Labor (revised)	–	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
New York Labor Dept. (proposed)	–	X	X		X	X		X		X	X	X	X	X	X	X	X	
Organizations, Institutions, and Industry																		
Brookhaven Nat. Lab.	1949	X	X		X	X	X			X		X	X	X	X	X	X	X
Western Union	1950	X		X						X				X				
Bell Laboratories	1952	X			X	X		X		X		X		X	X	X	X	X
Western Electric Tube Shop	1941			X						X			X	X	X	X	X	X
A.C.G.I.H.; X-R.S.F.	1951	X	X	X		X	X	X		X				X			X	
A.C.G.I.H.; Static Elim.	1953	X		X		X	X	X		X				X			X	
A.S.A.; Indust. X-ray	1946	X		X		X	X	X		X		X	X	X	X	X	X	
A.S.A.; Radium (proposed)	–	X			X	X	X	X		X				X	X		X	
		34	18	26	20	38	16	15	12	42	7	11	13	37	16	14	39	18

*Brief discussions of these codes and regulations are included in the bibliography.

sidering the available types of radiation sources.

Nuclear reactors. Many reactor sizes and designs are now being investigated for various purposes—power, radioisotope production, and as a radiation source. Each type has its own problems of shielding, waste disposal, and possibly air or water pollution. Especially since reactors are in such an early state of development, specification codes would be a retarding factor.

Machines, e.g., accelerators. Output-intensity control is easily accomplished by adjusting the electric power supply. Any code establishing power limitations must be very detailed and all-inclusive. Shielding regulations would have to recognize the wide variations in power and shielding-material absorption characteristics, as well as possible changes in permissible levels.

Encapsulated radioactive material. This material presents an inhalation and ingestion hazard due to possible rupture of the capsule. A code outlining specific control techniques against external hazards would require extensive shielding schedules of a varied nature. In addition, adequate ventilation or frequent checking to certify the integrity of the encapsulation would be necessary.

Loose, bulk radioactive material. This material, through danger of external exposure, ingestion, or inhalation, presents the highest hazard of all source types. A specification code needs to recognize the biological effectiveness of various radiations as well as shielding problems mentioned previously.

Analysis of Regulations

Although the existing regulations analyzed are categorized as a specification or performance approach, they vary widely in some essentials. The variations are in great measure due to the level of governmental jurisdiction, the specific interest of the agency, and the intent to educate or regulate. In the table, items used for control in 46 regulations are analyzed from the standpoint of the administrative agency.

Federal agencies. At this writing, there is no all-inclusive Federal regulation that would be generally applicable to all radiation sources and all places. Although the AEC is unique in its responsibility for protecting against radiological damage from most artificially made radioactive materials, its regulations follow the same pattern as those of other Federal administrative agencies.

These regulations agree on a "performance" approach in which a numerical standard is adopted, and in which the presence of radiation must be made known to the agency or to those potentially affected. Specific exemptions are made by all except by the Fair Labor Standards Act, which is so inclusive that a rigid interpretation would prohibit employment of minors even where the degree of hazard is equivalent to that of naturally occurring radioactivity.

NBS handbooks. Certain of these codes were designed to establish standards (performance) and others were designed to control a specific hazard from a specific source (specification). The basic approach, however, of all National Bureau of Standards handbooks is the education of those concerned.

There is some confusion as to which code should apply in a given instance, and large gaps still exist for specific problems. The biggest contribution of these handbooks has been in the establishment of exposure standards. Although not always applicable from an administrative standpoint, many handbooks have been incorporated in toto in several governmental codes.

Enforcement of the handbooks usually requires a qualified expert, since they were not designed as legal documents. Also, while the codes are of relatively recent origin, many are in need of revision. This is particularly true of the specification codes and demonstrates their major weakness.

States and municipalities. This group of agencies has made maximum use of licensing the users of radiation devices for fees. They ordinarily applied whatever standards were available for a specific hazard, rather than developing their own, and merely defined the administration and enforcement of these standards consistent with agency policy.

The field of interest of state and local agencies has been almost exclusively the control of the X-ray shoe-fitting fluoroscope hazard. Details vary considerably, but, essentially, the regulations conform to the pattern of a rigid specification code.

Recognition that a larger responsibility exists for other radiation hazards is of relatively recent origin. Many of these same agencies are now actively studying radiation exposures of the public or of the worker to a much larger variety of radiation sources.

Industries, institutions. There is evidence that specification-type rules are invoked by industry when only one type of source is used within the plant, but that performance-type codes are developed where multiple radiation hazards exist.

The guides proposed by the independent American Conference of Governmental Industrial Hygienists implement the work of the National Committee on Radiation Protection. This hygienists' organization offers to member agencies guides aimed at obtaining uniform regulations on specific problems. Many of the state and municipal regulations on X-ray shoe-fitting

Exposure Limits

As more people become responsible for administering radiation-protection regulations containing "maximum permissible" dose or concentration limits, it becomes increasingly important that the assumptions and implications of such figures be pointed out.

Unfortunately, there is a tendency to interpret these figures as conditions that are "permitted," i.e., exposures that can be considered as completely safe and that can be received right up to the stipulated maximum at all times. Obviously, this is not the intent. Also, "permissible" implies a man-made statute, a limit that has legal significance but not necessarily natural. Persons receiving more than the value established for the exposure situation are then breaking a law, and might be subject to fine. In preparing codes that have the force and effect of law or statutes themselves, such terminology may be appropriate.

It is recognized that the selection of proper words to express the concepts implied in setting down numerical limits is exceptionally difficult. In some manner, it should be made apparent that radiation dose has some natural limit and may result in damage under certain conditions; not because human beings, no matter how expert, have decreed it, but because the laws of nature, physics, biology and medicine, are as they are.

fluoroscopes resulted from the direct adoption of the recommendations of this organization.

All codes make provision for indicating the presence of radiation hazards, and all indicate the need for competently trained persons.

Importance of regulatory items. The frequency of occurrence of the regulatory items in the various codes is indicated at the bottom of the table.

Notification that radiation is present without the use of instrumentation occurs most frequently. The employee, the employer, the responsible agency, or all three, must be informed that the radiation source is present and that some degree of hazard may exist. The next most frequent requirement is that a qualified expert be responsible for radiation hazard control.

The regulations also indicate the necessity of including numerical exposure standards. Some offer hourly dosage rates as the criteria for continuous weekly exposures; some codes specify concentrations in air or water as the permissible limits. Where general methods of safe practice or the type of instrumentation needed are stated, the administrative methods of obtaining such controls are usually clearly set forth.

Essentials of Radiation Codes

In establishing radiation protection regulations, every agency has specific problems of administration determined by its function and jurisdiction. The characteristics of radiation create additional problems and amplify existing ones. Any regulation intended to solve these problems must encompass certain essentials necessary for the formulation of an effective and reasonable code.

Jurisdiction. The jurisdiction of an agency developing a radiological health code must be clearly understood. If the code is intended for educational rather than enforcement purposes, it should be so stated. Penalties for failure to comply and the various weights of legal terminology should be made clear.

Standards. A code must specify some exposure limits, but there appears to be no way to insure uniformity. It is an essential that these limits, "maximum permissible," be clearly set forth, particularly in a broad, performance-type code. Since these limits are subject to change, provision should be made for easy revision.

The Need for "Qualified Experts"

While production and other technical personnel can accept numerical safety standards and develop suitable safety devices, their training in protection may have been minimal. These persons find it difficult to understand the basic assumptions inherent in many accepted standards, and some means must be found to give them the opportunity to use radiation in a safe manner. An essential step in this direction would be recognition of "qualified persons" who could be made responsible for proper interpretation of exposure standards for diverse types of radiation under many conditions.

Radiologists have pioneered in establishing criteria for certifying "qualified experts" in medical radiation exposure control. But many individuals lacking sufficient direct medical experience for such certification have significantly contributed to radiation protection. "Health physicists" in AEC programs have been trained specifically to handle many of the problems in radiological health. These persons, properly certified, could expedite radiological health in industry and might serve to supplement the work of the official agency.

Closely allied with the question of the "qualified expert" is the need to determine the technical competency of any employee. Many codes state that a "competently trained employee" shall be responsible for control of radiation hazards without clarifying what this terminology means.

Many training programs in radiological health are now underway, but these are oriented for the most part for official-agency personnel currently engaged in other duties. This training, by agencies and educational institutions, is being given without clarification of the degree of proficiency a graduate obtains in terms of either the "qualified expert" or "competently trained employee" concept.

Where regulations are directed toward protecting employees, the establishment of different exposure limits for persons who may be significantly radiosensitive, such as minors or pregnant women, has been proposed. Outright prohibition of these individuals in areas of moderate radiation exposure may be the best solution.

Although technical definitions for radiation characteristics have been included in many codes, these may not be necessary since standard definitions are now available. The incorporation of legal definitions is most essential, particularly where the agency carries out definite enforcement procedures.

A performance approach has been most successful where the broad problems of radiation use are to be regulated against. In this type of code, exposure limits to employees are set regardless of the type or source of radiation. Where the agency wishes to solve only a specific problem, specification codes may be entirely satisfactory. This type of code may be circumvented by substituting a different component in the device being regulated and is not applicable to new problems.

Administrative rules. The formulation of proper administrative rules should include:

1. Knowledge as to the location and hazard potential of all radiation sources that may be considered hazardous.

Information to the agency should include, wherever possible, the number of persons possibly exposed, their estimated exposure conditions, the approximate degree of hazard, and the specific control techniques to be used. The data required must be sufficiently elastic to permit the use of radiation without unreasonable restrictions.

This raises the entire issue of registration or licensing by permit. Registration should be sufficient to alert the agency to the potential hazard and permit it to determine the future application of its rules. Blanket registration can be offered to users who show competency in controlling radiation hazards. Licensing is both restrictive on the agency and industry, particularly since the uses of radiation are so varied and numerous. Licensing may be possible only where control over one specific device exists, such as the X-ray shoe-fitting fluoroscope, but is not practical otherwise.

Workers should be informed that a radiation source is being used in their occupational environment. This is absolutely essential where distance and time are an integral part of the control techniques. The usual modalities of worker education, such as posting of

signs, on the job training, labels, etc., must be relied upon, but these may be modified according to labor relations in the specific plant. Full employee cooperation is essential in this program, as is full confidence in management's instructions in safeguarding.

2. Classification of sources by type and by degree of hazard is essential to the development of practical safeguards.

Classification should include specific exemptions and procedures to obtain exemptions for essentially nonhazardous devices using small quantities of radioactive material. When to apply film badges or dosimeters or to initiate routine air sampling or contamination control is highly dependent on the classification of sources and hazards, e.g., air sampling is not essential for radiation-producing electrical equipment.

3. A numerical working "exposure" limit must be included with provision for subsequent revision and for the effect that revision may have on previously approved installations. These limits must be in terms of exposure to personnel rather than amounts of radioactive materials because of the variation in radiation characteristics of different radioisotopes. One further problem is the development of satisfactory criteria to permit direct comparison of materials on the basis of the hazard potential, so that proper classification can be made.

4. Proper maintenance of records is also essential. These are of two types, environmental and medical. These records provide data for amending the code and add to the knowledge of human exposure to radiation. In the event of a lowering of the limits of exposure, such data in the proper hands would enable the higher exposures to be reevaluated and therapy (if available) to be applied.

The measures aimed at providing "medical" data must be reasonable and adequate. Under medical data is included dosimetry, physical examinations, and breath-radon measurements for radium workers. Routine blood counts are expensive and at the best only indicate radiation doses when they have exceeded reasonable limits; they also presuppose failure of the code to protect by other means. For this reason, coupled with classification of sources by degree of hazard, routine dosimetry, air sampling or surveys by a qualified expert should be recommended, whichever appears appropriate. Where final conclusiveness for exposure control must rest with medical determinations made on the person exposed, these should be performed at the discretion of the same expert. The proper calibration of film badges and dosimeters still is a large obstacle in their complete acceptance by many authorities. However, it can be stated that they are far superior in detecting low-level exposure to external ionizing radiation than the body tissue itself.

5. The extent to which reliance or authority is delegated by the official agency to a qualified expert should be determined. It would appear that these persons can greatly decrease the physical effort required to administer any radiation code. If the outside expert is not to be relied upon, the agency must have its own staff.

6. Finally, the determination of exposure conditions depends to a great extent on the electronic instrumentation used. Where possible, the limitations of instruments should be specified in the code. The greater the dependence upon qualified experts who understand these limitations, the less emphasis on education regarding measurement techniques will be necessary.

If an official agency will bear in mind these basic percepts and clearly resolve its own attitudes objectively, a reasonable yet protective regulation can be formulated.

New York State Code

An advisory committee was selected in January, 1953, to formulate a radiation code for the Labor Department under powers vested in the Board of Standards and Appeals. The draft has been considered by a Labor Department committee and will be presented in public hearing next month. After action on or rejection of comments made at the hearing, the code will be enacted by publication.

According to usual procedure, upon enforcement of a regulation, appeals can be made to the Board. These are processed at hearings or lead to reconvening the advisory group and possibly changing the code.

A Labor Department code is enforced chiefly by field inspectors of the Division of Industrial Safety Service. In other instances, local health or building agencies or the state police may be charged with enforcement.

Practically every state department—Executive, Taxation and Finance, State, Education, Labor, and Health—plays some role in safety. The Health Department is active in all fields of public health and some fields of occupational hazard where the Labor Law does not apply.

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NBS Handbooks

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Ultimate Disposal of Radioactive Wastes

Montmorillonite clay selectively adsorbs fission-product cations. The radioactive ions can then be sealed within the crystal lattice by heating to 1,000° C. These are the basics of a new process for storing radioactive wastes

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ULTIMATE DISPOSAL of highly active fission-product wastes with long half-lives presents serious biological, sociological and economic problems (*1*). Experimental investigations here have been directed toward developing a process for the confined storage of fission wastes, using naturally occurring stable materials, particularly clay minerals of the montmorillonite group. This article presents the results of studies on ion-exchange properties of the clay, fixation of radioactive ions in the clay, and development of essential process designs.

The most prevalent disposal method for fission-product wastes is to hold them in underground tanks. Temporary adsorption of ions on soils and slowness of ground water flow may lessen the ever-present danger of leaks and breaks in the tanks. But there is no adequate information on which to estimate the safety or permanence of storage in tanks as a long-range disposal procedure. Much more needs to be known about such factors as corrosion in the tank systems, adsorption on soil and rock, and ground-water flow.

There is probably no great lack of agreement to the effect that a new and more permanent method of disposal is needed and much to be desired, but it will probably be necessary to show that any new method is superior in both permanence and cost.

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TABLE I Relative Adsorption Efficiency

Foreign salt	*p*H	*R* Y^{91}	*R* Cs^{134}
$Mg(NO_3)_2$	6.5	1.7	14.1
$Al(NO_3)_3$	2.9	0.2	7.1
$NaNO_3$	2.0	35.0	43.2
$NaNO_3$	4.0	67.6	54.8
$NaNO_3$	6.0	81.0	46.4
$NaNO_3$	8.0	52.9	42.4
$NaNO_3$	10.0	9.4	31.4
$NaNO_3$	12.0	0.7	26.2

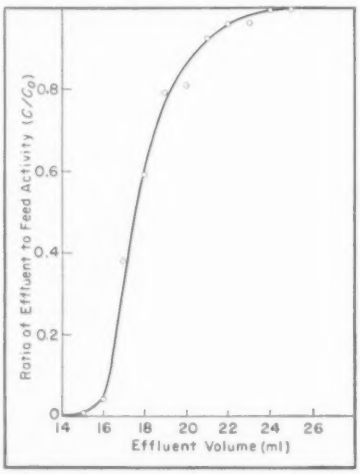

FIG. 1. Clay-column performance is shown for column containing 0.3156 gm clay. Solution used is 0.02M CsCl

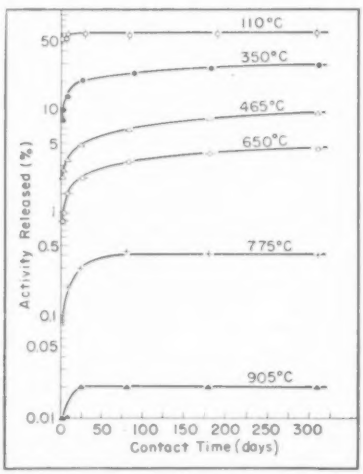

FIG. 2. Leaching of Ce^{144} from heat-treated clay with synthetic sea water shows treatment temperature effect on fixation

A study of one possible method of achieving permanent and safe disposal of radioactive wastes, particularly the long-lived fission products, is presented in this article. Briefly, the method is based on the adsorption and fixation of radioactive ions in montmorillonite clay. The advantages of using this clay are: capacity and selectivity as a cation exchanger, relatively low cost, ease of process handling, and chemical and physical stability before and after heating and radiation exposure.

Adsorption Properties

The ion-exchange properties of montmorillonite-group minerals have been recognized and investigated for a number of years (*2–4*). The most plausible explanation of the exchange characteristics of these minerals is based on their fairly well substantiated layer lattice structure (*4*), the exchangeable ions being located between the lattice layers.

The clay used in these tests was a predominantly calcium saturated montmorillonite,* with an exchange capacity of 1.12 milliequivalents/gm. Actual capacity of the clay for various ions was determined by passing a solution of the carrier ion plus a tracer ion through a column made up of a coarse clay fraction. Tracers used were: Sr^{90}, Y^{91}, Zr^{95}, Cs^{134}, Ce^{144}, Pm^{147}, and aged mixed fission products. Typical sigmoid ion-exchange breakthrough curves, such as Fig. 1, were obtained. The clay capacity was found from the known weight of clay in the column and the area over the breakthrough curve. Some average values are: Sr^{++}–1.15, Cs^{+1}–1.10, Y^{+3}–1.07, rare earths^{+3}–1.12 meq/gm.

Selectivity of montmorillonite for fission products in the presence of relatively high concentrations of foreign ions was studied using Y^{91} and Cs^{134} as tracers and Na^{+}, Mg^{++}, Al^{+++} and H^{+} as interfering ions. The relative efficiency of tracer adsorption from solutions flowing through clay columns at a constant flow rate is given by $R = V_0/W$, where V_0 is the effluent volume at a specific activity ratio of 0.02 (arbitrarily chosen breakthrough

* The clay used here was generously provided by the Filtrol Corp., Los Angeles, Cal., and designated as Filtrol X519 (R2532). Fullers earth, a Wyoming bentonite, and an acid-activated montmorillonite were also examined but were inferior to R2532.

Preparing Clay Columns

FIG. 3. Steel syringe is used to extrude a continuous rod of clay-water paste

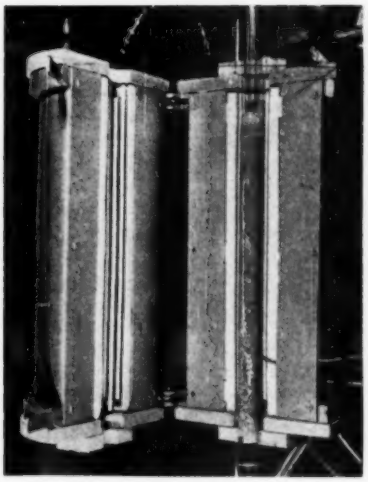

FIG. 4. Clay column contains $\frac{1}{16}$-in. clay rods, supported by a glass-wool plug

PROBLEM. *Montmorillonite clay in its raw state readily breaks up into finely divided particles, from 1–10 microns in size. Because of the large surface area, a bed of this material is impervious to fluids. When suspended in water, the particles do not settle out readily, even under quiescent conditions. Much of the chemical investigation on the clay was done by batch contacting, followed by centrifugation. Complete separation of solid and liquid phases is imperative, as, after treating wastes, the clay becomes highly radioactive.*

Batch contacting is undesirable for full-scale operation for these reasons: 1, only one equilibrium step is accomplished with each contact, and many steps are required for effective decontamination; and 2, operating and maintaining high-speed centrifuges under intense radiation fields would present serious mechanical problems.

SOLUTION. *Continuous-flow processing was made possible by devising a way to prepare clay columns made up of stable clay aggregations. This is done in the following manner: Clay and water are mixed in the ratio of 10 gm to 7.3 gm, respectively. The small moist crumbs that form are put inside a steel syringe (Fig. 5). The clay is extruded directly into a column container filled with water. The continuous clay rods break into short lengths that pack rather loosely in the container as shown in Fig. 4. The rods present large passageways for fluid movement, and at the same time allow liquid contact (and ionic interchange) between the fluid in the passageways and the discrete particles within the rods.*

The clay aggregations are suprisingly stable in water. Addition of a small fraction of one of the commercial soil conditioners (0.5% Krilium) increases the stability considerably, but is not necessary unless the column is subjected first to high-ionic-strength solutions and then to low-ionic-strength solutions. Although formation of clay-water aggregations and their subsequent stability is of great importance in this waste-disposal investigation, no attempt has been made to study the interaction as an end in itself. Crumb formation in ion-exchange clays has been noticed previously (7).

In analyzing column ion-exchange performance, column diameter probably should be considered, along with column height, clay-rod diameter, and solution flow rate. This is because in larger-diameter columns, rod orientation would shift in favor of a more nearly horizontal position.

TABLE 2—Leaching of Long-Lived Fission Products

Cation and tracer	*Replacement solution*	*Contact time (days)*	*Fixation temp. (° C)*	*Activity released (%)*
Sr^{89}	0.5*M* $BaCl_2$	2	110	100
		42	875	0.1
Ce^{141}—Pr^{144}	Sea water	200	110	57
		200	905	0.02
Zr^{95}—Nb^{95}	0.1*M* HNO_3	100	110	25
	0.04*M* $ZrO(NO_3)_2$	100	920	0.04
Cs^{134}	Sea water	350	950	0.1
Y^{91}	Sea water	340	880	1
MFP*	Sea water	60	915	0.11
	6*M* HNO_3	80	835	10

* Mixed fission products about 3 years old. Approximate composition—rare earths —57%, Sr^{90}—27%, Cs^{137}—10%, Ru^{106}—6%.

point) and W = clay weight. Table 1 lists some R values. From these and other experiments it appears that low R values are associated with high multivalent-ion and hydronium-ion concentrations.

Because the exchange reaction is reversible in the presence of high concentrations of foreign ions, it was necessary to devise a method for immobilizing the exchanged fission-product ions to yield a chemically stable product suitable for utilization or ultimate disposal.

Fixation by Heating

Fixation of the exchanged radioactive cations in nonreplaceable form was carried out by heating the clay to high temperatures in a muffle furnace. High-temperature treatment can also be accomplished by passing the clay particles through the flame of an oxygen-illuminating gas torch (*5*). Spheres 0.5–40 microns in diameter, with virtually the same chemical stability as the furnace-treated product, result from the gas-flame process, although the furnace-treated product has a crystalline structure, and the spheres yield an X-ray diffraction pattern typical of a glass.

Structural changes induced in montmorillonite by thermal treatment have been described qualitatively (*6*). Above 900° C the characteristic layer lattice structure is destroyed. This is accompanied by the appearance of a new phase identified as crystalline SiO_2. Entrapment of ions within a crystallizing SiO_2 lattice could thus explain high-temperature cation fixation.

The degree of fixation achieved by heat treatment was measured by contacting the treated clay with a large excess of replacing solution (most frequently synthetic sea water), and comparing the activity released with the total activity in the clay. Table 2 lists representative results of replacement tests involving various long-lived cations. Figure 2 shows the replacement of Ce^{144} from heated clay.

To interpret the replacement experiments the following processes for transfering radioactive cations from the clay phase to the solution phase should be considered: 1. interlattice ion exchange; 2. surface or broken-crystal ion exchange; and 3. hydrolysis of the clay mineral resulting in mass transfer to the solution.

In determining the release rate of exchanged cations, the composition of the contacting solution with respect to ionic size, charge, and composition is significant. Qualitatively, isovalent ions that are least hydrated are most firmly bound to the clay and thus are more difficultly replaceable. Conversely, small ions are more effective replacing agents than are large ions. Also, for ions of the same size, multivalent ions are bound more strongly than monovalent ions (except for the hydronium ion that behaves like a multivalent ion). Most of the cationic fission products should be rather firmly bound since they are primarily multivalent or are small unhydrated ions.

Experimental curves of activity removed vs contact time usually show an initially rapid activity release followed by a slower and, for higher fixation temperatures, often imperceptible activity release (Fig. 2). It is thought that the major process responsible for the initial portion of the low and intermediate temperature curves is the more or less straightforward interlattic ion-exchange reaction. After high-temperature heat treatment, hydrolysis and surface exchange became the dominant mechanisms. The second, more gradual, portion of the high-temperature curves is believed associated with the release of "fixed"-interlattice ions and continued hydrolysis of the mineral.

Processing Studies

After the chemical studies demonstrated the cation-exchange and fixation properties of montmorillonite clay, work was directed toward developing large-scale equipment for conducting the process. Procedures for preparing clay columns were devised, as explained on page 15.

The ion-exchange efficiency of clay columns was tested with a synthetic fission-product solution. Before introducing the test solution, distilled water was forced upward through the column to remove any suspended clay particles. Water remaining in the column slightly diluted the test effluent, but dilution was probably only 25 ml of the 1–3 liter column throughput.

The synthetic fission-product solution used in the tests contained Sr, Zr, Y, Ba, La, Ce, and Pr nitrates and Cs and Nd chlorides. Total concentration of these salts was $5 \times 10^{-3}M$. Sodium nitrate (0.2*M*) accounted for most of the ionic content. Tracer amounts of aged fission products† were added to the synthetic solution, to yield feed solutions with activities from 10^4 to 2×10^5 cpm/ml (10% counting yield).

In the first run neutral synthetic fission-product solution was fed to a single column; performance is shown in Fig. 5. The feed solution had an activity of 13,940 cpm/ml, while the combined product effluent gave 2,409 cpm/ml after some 50 column volumes of solution had been treated. Presumably, a slower flow rate through a longer column would yield better decontamination. This is seen in the

† Fission-product solution was obtained from the Oak Ridge National Laboratory.

results of the second run (Fig. 6) in which three columns in series were employed. In the third run (Fig. 7) the *p*H of the feed solution was adjusted to 4.14, as compared with a *p*H of 3.25 for the second run. At the higher *p*H and the same flow rate as used before, effluent activity was less than $\frac{1}{50}$ of feed activity after about 2 l of solution had passed through the system. The results of these experiments do not denote any limitations in the capacity of clay columns to remove fission products from waste solutions.

Clay selectivity for certain ions is shown by the removal of fission products of $5 \times 10^{-5}M$ concentration from the solution in the presence of $0.2M$ $NaNO_3$. Even among the fission products themselves the clay exerted some selectivity. In particular, it was found that the activity of certain effluent samples increased with time. From the half-life and energy of the radiation, the element responsible was shown to be Y^{90}, daughter of Sr^{90}. Hence, a separation of Sr^{90} from Y^{90} was accomplished in the clay bed, and, consequently, the ratio Sr^{90}/Y^{90} in the effluent was, for a time, much higher than the normal 1-to-1 ratio in the influent. By following Y^{90} growth into the samples it was established that the clay gradually becomes saturated with respect to Sr^{90} long before complete activity breakthrough occurs.

Proposed Process

Figure 8 shows how montmorillonite clay might be used for removing cation activities from fission-product wastes. In principle, a number of clay columns would be connected in series and moved at intervals countercurrent to the waste-solution flow.

The more columns used, the more uniform the effluent, and, up to a point, the clay would be more nearly saturated with fission products before being removed for firing. Presumably, the fired clay would be stored in accordance with some carefully prescribed plan, or it might be used as a source of γ or β radiation.

If used as a γ source, the materials to be irradiated would not have to be brought into direct contact with the clay; however, if used as a β source, direct contact would be required because of the low penetrating power of β radiation. The extruded clay might be well suited to this application, for when it is heated to the desired tem-

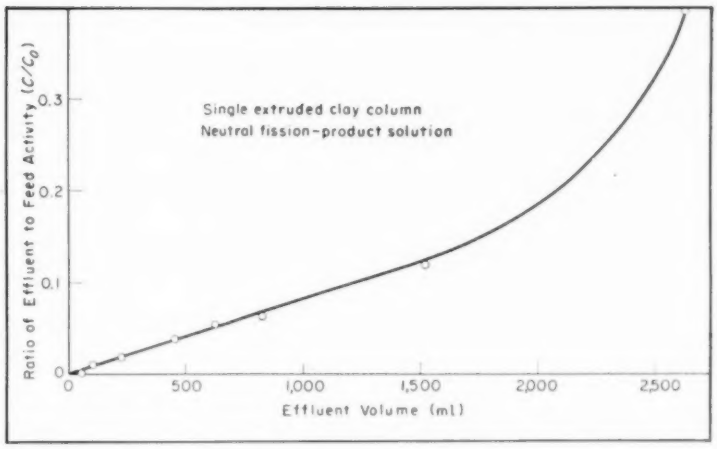

FIG. 5. Single column shows this performance with neutral synthetic fission-product solution. Column is about 1.5-cm diameter by 30-cm high; it contains $\frac{1}{32}$-in. diameter clay rods

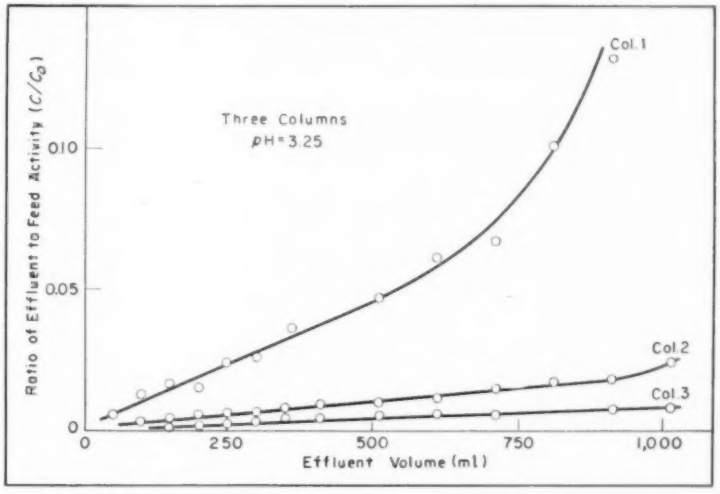

FIG. 6. Three columns in series decontaminate low *p*H fission-product solution better than single column at some flow rate

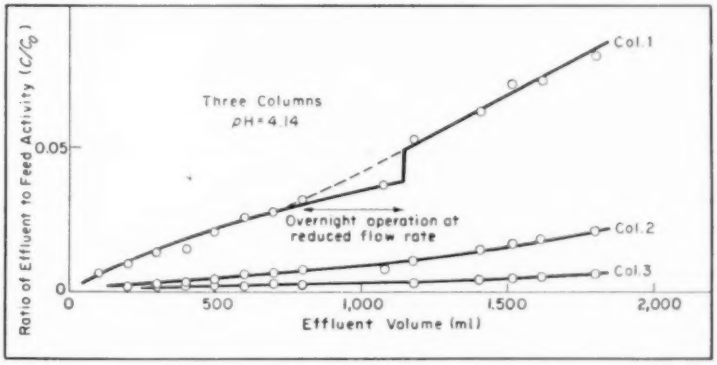

FIG. 7. Fission-product solution at higher *p*H is decontaminated even more effectively by three columns in series

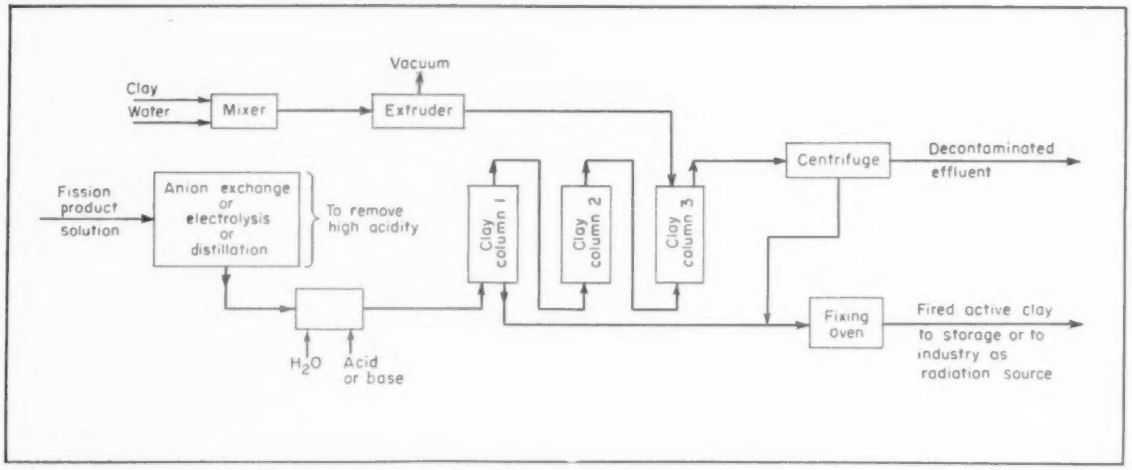

FIG. 8. In possible process for decontaminating fission-product wastes, column 1 is removed when saturated for firing of its clay; columns 2 and 3 are moved upstream. New column is added to replace column 3

perature of around 1,000° C, the rods retain their general shape and the column remains highly permeable to fluids. Fluids circulated through the column would be exposed to the β radiation. In addition, the removal of internal heat resulting from radioactive decay of the fission products would be facilitated by fluid flow through the permeable columns.

Discussion. The experiments to date have employed only synthetic fission-product solutions containing tracer amounts of radioactive fission products. It has been found that high concentrations of hydrogen, sodium, or ammonium ions are detrimental to the take-up of fission products by the clay. Therefore, if an acidic waste solution is to be treated, it would be desirable to remove the acid by a process such as anion exchange, electrolysis, or distillation, that would not introduce additional ions. These processes are under investigation. However, if they do not always prove feasible, dilution may be used to reduce the gross cation concentration.

Adsorption of anionic activities has not been investigated adequately. The clay may have some surface adsorptive power and may be able to remove a small amount of the long-lived anionic activity that occurs in fission wastes. It is very doubtful that the clay can exchange anions to the same extent as it exchanges cations. However, the long-lived activities are generally associated with cations rather than with anions.‡ Therefore, after first allowing a reasonable cooling period for the decay of short-half-lived activities, the clay process may prove sufficiently effective to be used for ultimate disposal of high-activity production wastes.

Economics. The economics of the clay process have not been worked out in any detail, but it is quite certain that considerable savings in the cost of disposal by this method may be possible if the inactive-salt concentrations of the waste solutions can first be reduced. Adequate disposal of fission-product wastes from large-scale atomic energy operations, therefore, might profitably be regarded as a final process in the operations. Otherwise, the problems of ultimate disposal may be unnecessarily difficult and complex.

* * *

The authors wish to acknowledge the very great assistance of G. P. Simon and B. J. Byrne who performed a large proportion of the laboratory work. This research was carried out under the auspices of the U. S. Atomic Energy Commission.

‡ With the possible exception of ruthenium this is true. The valence state of ruthenium in fresh and aged fission-product wastes is somewhat in doubt, and therefore few experiments other than exploratory ones have been carried out with this element. Greater emphasis is to be placed on the problem of ruthenium removal in subsequent work.

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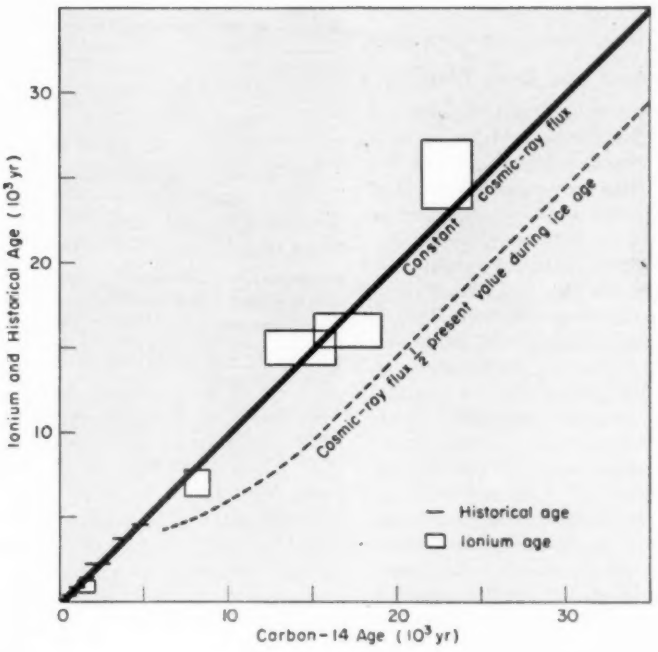
How Hanford Handles Laboratory Wastes

Hanford Atomic Products Operations research laboratories pipe radioactive liquid wastes to a central storage structure, where the wastes are loaded into 6,000 gallon tank-trucks. Wastes are transported to an isolated desert area and dumped into the ground. Ground-water flow carries wastes to the Columbia River, but only after time lapse measured in centuries. Radioactivity will have decayed to safe level, by then.



COMPARISON of radiocarbon ages with ionium (Th^{230}) and historical ages suggests the constancy of the integrated cosmic-ray flux

Low-Level Counting, Key to

Advances in Radiocarbon Dating

Here's how improved low-level counting techniques and deeper understanding of the basic assumptions have led to new dating achievements using C^{14}

By J. LAURENCE KULP
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CORRELATION of the many recent advances in radiocarbon dating was achieved at a conference held in Andover, Mass., October 21–23, that brought together the chief workers in the field.* About 40 physicists, chemists, biologists, geologists, archeologists and anthropologists traded ideas, techniques and problems. The conference was highly successful and may be the most important single event in the development of radiocarbon dating since its discovery by W. F. Libby and associates in 1947.

The conference agenda was divided into three areas: assumptions and basic problems, techniques, and dating results. This article will deal with all three areas, stressing the first two. Background information will be included to provide perspective. First, a summary of the present over-all situation as reflected in the conference proceedings will be given in the two following paragraphs.

It became clear that the basic assumptions of the radiocarbon method have been given considerable experimental support. Many of the sources of error may now be fully defined. Techniques of measurement have become so diverse and are progressing so rapidly that new areas of application are opening up by virtue of increased precision (factor of 10) and increased range (up to 50,000 yr). A large majority of the dates obtained so far can be readily integrated with existing knowledge of historical and earth science.

Some measurements have produced anomalies that have been traced either to faulty collection or to laboratory error (generally contamination by fission-product debris). A few remaining anomalies require further study, but it was generally agreed at the end of the conference that there are no major contradictions between C^{14} data and field data. After six years of investigation and over 1,000 measurements in several

* Sponsored by National Science Foundation, National Research Council, and the R. S. Peabody Foundation.

laboratories, the radiocarbon method of age determination appears established.

Assumptions and Basic Problems

There are two primary assumptions in the radiocarbon dating method: 1, the integrated cosmic-ray flux has been constant for the last 50,000 years; 2, the atmosphere-biosphere-surface ocean carbonate reservoir is mixed rapidly compared to the time scale of the method.

Constancy of cosmic radiation. It was generally agreed that theoretical arguments favor the constancy of cosmic-ray flux over long periods to within a few per cent, but the arguments are far from conclusive. A preliminary experimental attack on the problem was reported by **J. L. Kulp** (Columbia). Certain ocean-bottom sediments are sufficiently homogeneous that radium content varies smoothly with depth. This fact can be used to determine the excess ionium (Th^{230}) content chemisorbed on the surface of the sedimentary particles while falling through the water column. Decay of excess ionium can be used to date the time since deposition of a certain layer. It is also possible to date the layer by the radiocarbon method using the carbonate fraction (largely shells of microscopic animals that live near the surface of the ocean).

Cores that meet these requirements are rare, and their small diameter makes it necessary to cover a considerable time interval to obtain enough sample. Despite these difficulties good agreement, as shown by the illustration on page 19, between the carbon-14 and ionium ages was obtained back to 25,000 years ago. This suggests that both age methods are valid and that the cosmic-ray flux has not changed by more than 10–20% for any sustained period in the last 30,000 yr. Further measurements to improve precision and to extend experimental range re expected.

Mixing assumption. Early measurements by Libby showed the second assumption to be true within 5–10% for trees. Later Kulp found a similar constancy in additional trees, atmospheric CO_2, surface ocean carbonate and truly marine shells, the variation being within the experimental precision then available. The advance in precision occasioned by development of the gas techniques described in later paragraphs makes imperative an exhaustive redetermination of the modern assay.

Radiocarbon Counting Techniques

Technique	*Laboratory*	*Counting rate*		*Error on modern —24-hr count (%)*	*Ultimate range (yr)*	*Counter condition*
		Background (cpm)	*Modern (cpm)*			
Ionization chamber	Cal. Tech.	—	—	5	15,000	150 lb/in² CO_2
Screen-wall, solid-carbon, Geiger counter	Lamont (Columbia)	2.3	6.1	2	25,000	8 gm C
CO_2-CS_2 Geiger counter	Michigan	7	9	2	27,000	1 atm; 3½ in. × 14 in.
CH_4 proportional counter	Magnolia	4.6	10	1.5	30,000	0.8 gm C
C_2H_2 proportional counter	U. S. G. S.	2.3	10.7	0.8	40,000	1 atm; 1 l
CO_2 proportional counter	Humble Oil	13.5	45.2	0.4	45,000	150 lb/in²; 6 gm C; 1-mil-wire, 2-in.-diameter counter
C_2H_2 proportional counter	Lamont	12	65	0.3	47,000	1 atm; 4.9 l
Liquid scintillation	Chicago	30	80	0.3	48,000	20 cm³
CO_2 proportional counter	New Zealand	14	103	0.2	50,000	3 atm; 8 l

Some work has been done already. **G. J. Ferguson** (New Zealand) reported four new measurements on living trees from various elevations in New Zealand representing soft to hard wood. These were constant to 0.5%. **H. Suess** (U. S. Geological Survey) has measured three living tree samples from the east coast of the U. S. and one from Alaska and compared them with the expected value based on determination of 100-yr-old samples. The modern east-coast samples appeared to be lower than expected by about 1.5%. He attributes this to the increase in "dead" carbon from the combustion of fossil fuel during the past century. It was pointed out that atomic blasts might push the modern assay in the opposite direction. Hence, to determine very small differences between ages or slight variation in absolute age, it is essential that close contact on the modern assay be established.

Basic problems. One of the basic problems encountered in an attempt to do precise dating of relatively recent samples is the degree of fractionation of the carbon isotopes to which the sample has been subject. **H. Craig** (U. of Chicago) discussed this problem in considerable detail and showed that such an effect can be successfully monitored by measuring C^{12}/C^{13} ratios on the samples. These measurements are continually required in the acetylene and liquid-scintillation methods of radiocarbon assay because of possible fractionation during preparation. Craig further reported that the analysis of a variety of fossil woods for C^{12}/C^{13} showed no more variation than modern wood. The hypothesis that decayed wood might be fractionated was disproved by measurements on a selected set of decomposed samples. It now appears unlikely that fractionation effects amounting to more than a few per cent do occur. Since this amounts to a maximum absolute error of only a few hundred years regardless of the age of the sample, the problem is not significant for samples greater than 10,000 yr in age.

A particularly interesting anomaly has developed in the case of surface-ocean carbonate. Craig's C^{12}/C^{13} data predicts that surface-ocean carbonate should be about 5% higher in C^{14} than modern wood. Actually these two

sources appear identical in C^{14} content, which makes the ocean carbonate appear about 400 yr old. This suggests a slow rate of turnover for the oceans or dilution with ancient carbonate.

G. E. Hutchinson (Yale) described measurements on certain plants that live in calcareous inland waters. Submergent species, which utilize bicarbonate ions for their carbon source, show low values of C^{14} equivalent to an age error up to 2,000 yr. Emergent plants, which derive their carbon from the atmosphere, do not give anomolous values. These results emphasized again the need for extensive survey material for the modern assay and a critical selection of ancient material. Fortunately, it is relatively simple to recognize conditions or species that might lead to such errors.

J. Arnold (U. of Chicago) emphasized the importance of contamination of old samples by small quantities of recent matter in the form of rootlets, humic acid, etc. At 16,000 yr ago, 5% contamination by modern material would produce an age error of 2,000 yr. However, at 55,000 yr, 0.1% of recent material would produce an error of 5,000 yr. It was generally agreed that there is an age, probably not too far beyond 50,000 yr where the contamination with traces of modern carbon will become intolerable. On the other hand, some materials such as charcoal are more readily treated to remove traces of modern contaminants.

G. D. Smith (U. S. Dept of Agriculture) evaluated the possible effects of soil genesis in samples and emphasized the need for careful collection and description of the site.

Techniques

The early work on radiocarbon dating at Chicago, Michigan and Columbia used solid carbon mounted inside a self-quenching Geiger tube. Subsequently a number of laboratories including those mentioned have tried most of the other possible methods—ionization chambers, proportional and Geiger counters, and liquid scintillation counters. A major portion of the conference was devoted to an evaluation of each of these methods with the exception of the ionization chamber, which appears to hold little promise.

The critical data already obtained for each technique are listed in the table on page 20. Precision has already been improved by a factor of 10 and range doubled from the original screen-wall method. The most promising direction appears to be proportional gas counting, but the liquid scintillation technique is also potentially very powerful. The table shows the situation in each laboratory at the time of the conference with some minor assumptions on my part with regard to the background reproducibility in each case.

At the conference Kulp stressed the difficulties encountered in obtaining 2% precision with the screen-wall method. The most severe problem is the contamination of the carbon with airborne fission products. The other new techniques eliminate this problem entirely.

H. R. Crane (Michigan) emphasized the simplicity and reproducibility of the CO_2-CS_2 system. This method is limited to small anticoincidence rings and hence small-volume counters since long blanking times (3 msec) must be used.

W. H. Burke (Magnolia Research Lab.) developed the CH_4 proportional-counter method with a particular view to using small samples. He has developed a small counter that will compete in precision with the screen-wall method while using only 0.2 gm carbon. By increasing pressure he can readily achieve precision equivalent to the acetylene and CO_2 systems. Burke suggested a tiny high pressure counter to date samples as small as 50 mg.

H. Suess described his acetylene proportional counting system, the first gas system in routine operation to approach 40,000 yr in range. The counters are exceptionally stable, and the chemical preparation is not complicated although some safety precaution must be taken. Kulp described the behavior of acetylene counters ranging from 0.5 to 8 l. The method is quite versatile.

M. Williams and **H. R. Brannon** (Humble Oil Co.) emphasized the advantages of using CO_2 as the counting gas. The chemical preparation is simple and safe. For excellent counting behavior, the CO_2 is adsorbed and desorbed on and off pure CaO to remove trace impurities such as O_2, H_2O, SO_2 and the halogens. They found no inherent difficulty in operating at 10 atmospheres and expect to go higher.

J. Arnold described his liquid-scintillation counting system, which is now in routine operation. This method can, in principle, be pushed to very great sensitivity by simply increasing sample volume. However, the method involves the rather complicated synthesis of hexane and related hydrocarbons from CO_2, and the final product must be precisely assayed both for total carbon and for isotopic fractionation during processing.

G. J. Ferguson discussed his superior system based on the proportional counting of CO_2 in large volume counters at pressures up to three atmospheres.* His chemical procedures were similar to that described by Williams and Brannon. He employed an elegant electronic system consisting of four output channels designed to separate the C^{14} β spectrum into three parts and in addition directly monitor radon contamination. This system provides a most sensitive way of detecting spurious counts, counter-gas impurities, or radon contamination. As far as necessary techniques were concerned, Ferguson's report was the high point of the conference.

Dating Results

About one-third of the conference was devoted to interpretation of geological and archeological results so far obtained by radiocarbon dating. In general, radiocarbon dates fit all other data in each area. There are a few anomalies, but it was generally agreed that there are alternative geological or archeological theories that can reasonably account for the results. There was a general plea for more determinations.

Some well-established results of radiocarbon dating follow. The last continental ice sheet retreated across the Canadian border about 9–10,000 yr ago. The glaciations in mid-North America and western Europe were essentially contemporaneous. Man has been in North America at least 11,000 yr and in South America at least 9,000 yr. There were several "little ice ages" ranging from 6,000 to 200 yr ago. The archeological periods from 2,500 B. C. to 500 A. D. in Southern and Central America were essentially synchronous.

The conference closed with a resolution recommending another determination of the half-life of C^{14} by the group at the National Bureau of Standards.

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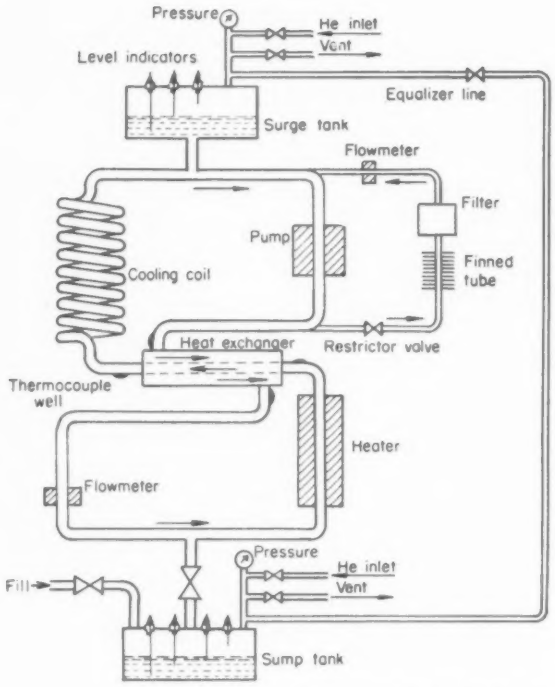
* An article by Dr. Ferguson, describing his radiocarbon counting system in detail, will appear in the January, 1955, issue of NUCLEONICS.

Components for Sodium or NaK Systems

Development tests at ORNL indicate that sodium systems must be designed, fabricated, and operated very carefully to prevent initial inclusion or formation of corrosion-causing oxides. Use of inert-arc-welded joints, electromagnetic or gas-sealed centrifugal pumps, and bellows-sealed valves yields a system with sufficient life for both scientific and industrial applications



TYPICAL small-scale experimental sodium system

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PHYSICAL PROPERTIES of sodium and NaK make these liquid metals particularly suitable as high-temperature heat-transfer fluids. Consequently, a new technology has been developed for handling them.* This technology involves various aspects of sodium plumbing,† including selection of materials and design of pumps, valves, heat exchangers, and instruments, as well as system design, gas blanketing, operating techniques and safety precautions. This article considers materials and components for use with sodium systems and relates Oak Ridge National Laboratory experience with the various components as developed at ORNL, Knolls Atomic Power Laboratory and Mine Safety Appliance Co.

A typical liquid-metal test circuit (less heaters, insulation, and instrumentation) is shown in the illustration on this page. Summaries of ORNL experience with particular components and the design, fabrication, and operation of sodium systems are considered here.

Heat Exchangers

Compact liquid-to-liquid and liquid-to-air heat exchangers have been built and tested. The tube-bundle arrangement in these designs allows for distortions caused by differential thermal expansion. Mechanical joints, although widely used in conventional heat exchangers, are not suitable for sealing high-temperature liquid metals. Thus all joints must be welded or brazed and must be of extremely high quality and soundness. High sensitivity mass-spectrometer leak testing is recommended between construction stages, although less exacting tests might be sufficient (e.g., rate of pressure drop or rise, under pressure or vacuum, respectively).

One countercurrent-flow liquid-to-liquid heat exchanger used NaK as both primary and secondary fluid and was operated between 1,000 and 1,500° F for over 3,000 hr. Both types 347 and 304 stainless-steel tubes were used; tube-to-header joints were cone-arc welded and Nicrobrazed. After the test, two tube failures were discovered in the Nicrobrazed tube-to-header joints. These failures appeared to have been caused by vibration and by the "etching" effect of circulating NaK on the tubes in the hot zones.

Radiators of all-welded construction employing large (~ 1 in.) finned tubes give reliable performance for conventional heat transfer applications. A compact sodium-to-air radiator, employing a crossflow arrangement with small finned tubes, operated at temperatures up to 1,700° F for several hundred hours. It was of stainless steel and was assembled by Nicrobrazing.

Electromagnetic Pumps

Both a commercially available electromagnetic pump (General Electric G-3) and a two-stage electromagnetic pump made at ORNL have been tested and used in experimental apparatus. The G-3 pump, as received, was limited to operation at less than 750° F, but it was modified to operate up to 1,400° F; flows of up to 16 gal/min have been obtained with heads of up to 22 lb/in². The two-stage electromagnetic pump was developed to provide up to 90 gal/min, although the attainable heads are much lower. General Electric manufactures, on a commercial basis,

* R. N. Lyon, ed., "Liquid-Metals Handbook" (U. S. Government Printing Office, Washington D. C., 1952).

† Sodium and NaK systems are sufficiently similar that, unless otherwise mentioned, statements about Na also apply to NaK.

Summary of ORNL Experience with Sodium-System Components

Structural Metals

Oxygen (in Na, scale, or inert gas above Na) forms Na_2O, which intergranularly attacks hottest parts of loop; it can be minimized by carefully fabricating and operating system and by using cold trap and purified gas.

If Na is kept free of O, most structural metals resist attack; however, there are little data from systems with high flow rates (100's of ft/min) or large temperature drops (>300° F). Isothermal static tests show that Fe, some stainless steels, Ni, and some Ni-base alloys (incl. Inconel), Mo, Ta, W, Cb, Co and some Co-base alloys are suitable for extended use up to 1,850° F. Convection-loop tests (of S.S. types 304, 310, 316, 347, and 446, Ni, Inconel, L-605, and alloy 1010) showed that most S.S.'s were intergranularly attacked only slightly, if at all, after 1,000 hr with hot-leg temperatures of 1,500° F, cold leg at about 1,300° F, and flow rate of 4 ft/min. Mass transfer does not appear to be severe, at least with flow rates and temperature gradients used to date.

Joints and Closures

Welds. Very clean sound welds are more dependable than other joints at high temps., but it is inconvenient to cut them for circuit changes (all repairs must be made with inert gas in the system). Poor welds, even if they don't leak at once, might limit system's lifetime by allowing oxide formation, which increases corrosion greatly.

Flanged joints. Leaks eventually occur in most such joints, largely because gasket relaxes after repeated temperature cycles. Where they have to be used (as in parting faces of pumps), they should be in coolest regions. Bolts, nuts, and gaskets should be chosen for appropriate combinations of thermal expansion and nonsticking properties. S.S. gaskets and Inconel-X bolts with S.S. nuts have been used successfully. Although leak prevention is difficult, API-type oval-ring gaskets (S.S. or soft Fe) in tapered grooves have been used successfully up to 1,500° F. Cu gaskets dissolve in Na. Tapered joints without gaskets are best flanged joints. External clamps (e.g., special C-clamps) remain cool, retain resilience, and add dependability.

Flared joints. This type, and compression joints, are suitable only for small (½-in. o.d.) tubes. The "Swagelok," a commercially available compression joint, has proved quite reliable for joining tubes.

Expansion joints. No suitable packing material; thus, to allow for thermal expansion, bends or bellows are used.

(Continued on next page)

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several two-stage pumps that have flow rates of up to 30 gal/min, and Allis-Chalmers recently constructed one designed for 4,000 gal/min at 100 lb/in².

The G-3 a-c pump was modified to use a flexible secondary conductor. Flows of about 16 gal/min at 5 lb/in² were obtained at 890° F. Performance tests substantiated GE data. Efficiency increased linearly from 0.5% at 2 gal/min to about 3% at 14 gal/min. Although data were taken at lower temperatures, most of the endurance run was at 750° F, the recommended maximum. At 1,000° F, the pump failed when a current lug melted loose from the cell wall. To obtain extended operation at 1,300–1,400° F, the pump cell was modified to reduce resistance where the leads were welded externally to the cell. Holes were cut in either side of the stainless-steel pump throat, and Inconel rod was used to weld nickel lugs into each hole. Current then passed directly from the nickel leads to the sodium, thus alleviating local heating.

The two-stage a-c pump developed at ORNL is essentially two pumps arranged in series, but it has only one magnetic flux loop and one current loop, each intercepting the fluid path at two positions. Currents of about 7,000 amperes at about 0.5 volt were used, along with a magnetic field strength of about 4 kilogauss. Without supporting structure, the pump is about 30 × 27 in. and, because it pumps 1,500° F sodium, the cell is type-316 stainless steel. The current loop contains copper buses with nickel spacers between the copper and the nickel cell lugs. Efficiency is improved by eliminating any magnetic material within 3 ft of the pump. With NaK, the pump delivered 90 gal/min at about 10 lb/in². The pump has given entirely satisfactorily performance.

Centrifugal Pumps

In the gas-sealed centrifugal pump, the difficulties of direct sealing of the liquid metal are avoided. A liquid-gas interface is maintained above the pump impeller, and only a gas seal is required around the shaft. Obviously, the pump can only operate with the shaft in the near-vertical position. It does have a distinct advantage, however, in that the pump sump also can function as the system surge tank. This type of pump has proved quite reliable for high-temperature (1,500° F) operation; it leaks no fluid and, with a good seal, only a negligible amount of gas.

Two sizes of gas-sealed centrifugal pumps were tested at ORNL. One had a capacity of 12 gal/min; the other pumped up to 250 gal/min.

The 12-gal/min pump operated over 4,000 hr at temperatures up to 1,500° F. It used three different gas seals: 1, a stuffing-box seal; 2, a rotary-face seal of Graphitar-30 operating against hardened tool steel; and 3, a rotary-face seal of Morganite MYIF (a silver-impregnated graphite) operated against hardened tool steel. The stuffing-box seals, in which Teflon and graphite-impregnated asbestos were used, leaked appreciable quantities of gas and required periodic maintenance. Both face-type seals proved satisfactory, but Morganite MYIF is slightly preferred to graphite because of the former's self-lubricating properties. Although regular dropwise lubrication with spindle oil (6–8 drops/day) was employed initially, lubrication was subsequently employed only when power fluctuations occurred.

The 250-gal/min gas-sealed sodium pump operated satisfactorily at high temperatures. It functioned in a stable manner, and priming, vortexing, and degassing problems were easily

Summary of ORNL Experience with Sodium-System Components (continued)

Insulation

Although most insulating materials react with Na, Johns-Manville Superex, Philip-Carey Hi-Temp. No. 19, and lead-mill or steel-mill wool slag are suitable for 1,500° F applications; they have good insulating properties and are relatively inert to Na.

Pumps

Electromagnetic. Preferred where cost and application (head vs flow) allows. They have no moving parts (thus, quite reliable), but are inefficient, especially at low flow rates. Two types of EM pumps were used experimentally at ORNL. A GE G-3 pump limited to <750° F was modified to function at 1,400° F; flows up to 16 gal/min were obtained with heads up to 22 lb/in². A two-stage EM unit made at ORNL pumped up to 90 gal/min, but with heads lower than the G-3's.

Centrifugal. Most efficient; gas-sealed versions are reliable; they leak no fluid and little gas (with a good seal), but must be nearly vertical. Alignment of shaft and seal housing must be preserved. Lack of a suitable packed seal limits these pumps to the larger gas-seal varieties. A small pump with 12 gal/min flow rates was used for 4,000 hr to test gas-seal modifications with Na up to 1,500° F; a larger version pumped up to 250 gal/min.

Canned rotor. Although otherwise suitable for high-temperature Na service, these pumps cannot be used over ~1,000° F because of thermal damage to insulation on motor windings. Head-vs-flow characteristics were unchanged, but maximum over-all efficiency decreased from a value of 35.7% to 27.3% when a normal pump's two ¾-hp motors were modified so that 10-mil-thick cans fit inside the motor stators. Armatures were machined to have 12-mil clearance. Operation was satisfactory with 400° F NaK.

Valves

The problem of seal leakage can be avoided by using seal-less valves. To prevent valve faces and seats from self-welding, locate valves at circuit points where temperature is 1,200° F or less.

Bellows sealed. Most satisfactory valve-stem seal for Na or NaK; no fluid leakage. Commercially-available valves of this type used routinely include those made by Wm. B. Powell, Fulton Sylphon, and Crane companies. A single bellows is usually filled with liquid, but a double-bellows arrangement with an entrapped gas between bellows is better. Some self-welding is experienced at 1,500° F; more torque is needed to open valve; no corrosion or self-welding troubles at 1,200° F. No difficulty for throttling at high temperatures.

Ball check. Successfully transferred 1,400° F fluids unidirectionally. Balls were type-440 (passivated) S.S., and housing and fittings were of type 316 S.S. Balls stuck slightly in open position, but pressure or tapping corrected condition.

Packed seal. No satisfactory valve packing was found. Leaks occurred through: graphite powder at 600° F under 10-lb/in² Na pressure; soda ash at 1,300° F under 10-lb/in² Na pressure; Met-L-X after 2 hr at 1,500° F under 15-lb/in² Na pressure; Amosite asbestos after 21 hr at 1,500° F under 15-lb/in² Na pressure. Although Pb-mill slag and Ni metal powder did not leak after 10 days at 1,500° F under 15-lb/in² Na pressure, the tests were discontinued.

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handled. The sump tank served as system surge tank. The gas seal consisted of an oil-flooded Graphitar-30 ring floating between two hardened-tool-steel surfaces, with contact maintained by a bellows spring. Coolant circulating in three regions near the seal kept wear faces at low temperatures. The pump was modified to provide: adequate clearance for level-control probes (to prevent electrical shorts), reinforced guide vanes, a labyrinth between interface and seal, baffling to reduce liquid turbulence, and a parting face in the pump casing above the liquid level.

Welding Techniques

Examples of special welding procedures include: an inert-gas shielded-arc d-c process, negative electrode, with a machined, cleaned, and unstressed base metal; filler of 1/16–3/32-in. rod (Inco No. 32 for welding Inconel; same material as base metal for stainless steel); 1/16–3/32-in. tungsten electrode with a 90-deg point; one to five passes with the work rolling horizontally or fixed vertically or horizontally; lap joints flush at weld and 3/32–1/8-in. clearance at butt joints with 100-deg bevel; shielding blanket is pure argon (<15 ppm O_2) flowing at 35 ft³/hr; beneath the weld the blanket is pure helium (<15 ppm O_2) flowing at 4–12 ft³/hr. The welder must be specially trained and qualified to extremely exacting requirements.

Sump and Surge Tanks

Both sump and surge tanks usually are included in large liquid-metal systems, but sometimes the sump tank is omitted and/or the surge tank is incorporated in a vertical shaft gas-seal centrifugal pump.

The sump tank stores the liquid metal between runs and is the lowest point in the system. It contains an inert atmosphere (usually helium) and has temperature and pressure instrumentation, heaters, insulation, gas pressure and bleed connections, and level indicators.

The surge tank provides expansion volume for the liquid sodium (which expands 20% from 250–1,500° F) and is at the top of the circuit. When separate from the pump, the surge tank usually precedes it in the system. Its auxiliaries are similar to those of the sump tank. The liquid metal must be prevented from boiling or vaporizing excessively, since such vapors condense and plug the gas lines.

Heaters

Because sodium must be above 208° F to be liquid, system heaters and insulation are vital parts of a sodium system. Some of the NaK alloys are in liquid form at room temperature and, thus, do not require heaters. For test runs, readily available units can heat systems to well over 1,000° F. Externally mounted insulated resistance-wire heaters generally are adequate, although direct resistance heating sometimes has advantages.*

* Despite the apparent hazard, Harwell uses steam to heat their sodium systems.

Thermocouples

Thermocouples can be attached outside containers or inserted in wells. Temperatures up to 2,000° F were measured by chromel-alumel couples and recorded on multipoint Brown recorders. Accuracy depends on fabrication and installation. If recorders are calibrated frequently, temperatures are measured within ±5° F between 0–2,000° F. Commercially available temperature regulators can maintain temperature to within few degrees.

Level Controllers

Generally, any level-indicating device can be adapted to level control; but only spark-plug-type probes and the variable-inductance float device have been routinely applied to automatic control of liquid-metal levels.

Spark plug. Preferred method. Rugged and simple, but level oscillates at least ¼ in. and indication is not continuous. Commercial plugs with extended electrodes provide leaktight lead through container wall, and cooled risers prevent shorts. Spark-plug ceramic fails in hot sodium, does not fail in hot gas.

Variable inductance. Continuous level indication, but maximum temperature was limited to 1,300° F. 1,500 hr operation gave no trouble and, by using limit switches on the indicating millivoltmeter, level was maintained within 0.5%. Calibration at desired temperature is necessary.

Resistance. Simple, rugged, and gives continuous level indication, but readings fluctuate. Undependable.

Gas bubbler. Sensitive to 0.04 in., good response. Continuous gas bleed makes gas line badly susceptible to plugging and puts premium on extreme purity of gas.

Resonant cavity. Although measurements were only simulated, indication should be continuous and accurate.

Flowmeters

Electromagnetic. Most suitable. Mounted external to fluid pipe; continuous, accurate, and dependable; head loss is negligible. GE makes satisfactory commercially available unit.

Venturi. Simple, dependable, no moving parts in liquid, but pressure measurement necessary.

Rotameter. Continuous, accurate, enclosed system, but it cuts off at low flows and maximum temperature of fluid is 1,300° F.

Rotating vane. Enclosed system, but unsuccessful because signal small compared with background; max. temperature limited to 750° F. Development suspended because of success of EM and variable-inductance Rotameter flow meters.

Pressure-Measuring Devices

Bellows. Null-balance, direct measurements, high temperatures, commercially available (Moore Products Co.). Need for small but continuous gas flow is a disadvantage. Pressures up to 70 lb/in² have been measured.

Diaphragm. Null-balance, direct measurements, high temperature (1,040° F); but needs continuous gas flow and is less sensitive than bellows. Pressure range: 0–40 lb/in².

Bourdon. Inexpensive, but temperature limited, and a trapped-gas volume is needed.

Manometer. Accurate, but fragile; temperature limited, requires a trapped-gas volume.

Satisfactory service is obtained from several kinds of external heating units, including: 1, prefabricated integral heater and insulation assemblies; 2, flexible heating cable wrapped around the object to be heated; and 3, Calrod-type heaters. Limiting temperatures (750–1,800° F) are determined by the heating elements, and depend on the lifetime desired. The integral assembly, which can be made in many sizes, can be clamped quickly on the part to be heated; such heaters have operated more than 1,000 hr with filament temperatures of 1,800° F. The flexible heating cable can be tightly wound on geometrically complex surfaces and can be used with filament temperatures of 1,500° F. Commercially-manufactured Calrod-type units vary widely in quality, but the GE units have been most satisfactory.

Resistance heating is attractive because direct-resistance methods uniformly heat constant-cross-section equipment. With this method, heater failures are eliminated, and very high heating rates are obtainable. Sections of 1-in.-IPS pipe 6 ft long have been heated to 1,500° F, and convection loops have been heated above 2,000° F for hydrogen firing. Where applicable, resistance heating is generally superior to other types, since heat is generated internally at the point where it is desired and the need for heat conduction by air or other gas is eliminated.

Conclusions

Although the sodium-system technology is in its infancy, it has already developed to the point where circulating-sodium heat-transfer systems have been successfully operated for several thousands of hours. Whether or not—in any given application—the use of sodium would effect the most economical process can be determined only by thorough analysis. However, many of the components required for any sodium system have been developed; most of them perform satisfactorily and give every indication of having sufficient life to be useful in industrial applications. Subsequent improvements, which reasonably can be anticipated in so youthful a technology, can only serve to enhance the use of sodium. Even now, the sodium system can be fabricated from any one of a number of commercially available structural metals, the choice being dependent upon strength and fabricability, since corrosion of most structural metals in sodium is negligible. In addition, many commercially available items, such as valves and instruments, are suitable for use with sodium. The unique developments upon which this successful use of liquid sodium has depended include: 1, adaptation of a pump to liquid metals; 2, fabrication methods; and 3, operating techniques.

* * *

Except for the corrosion data, which was obtained from studies directed by ORNL's metallurgy division, the work reported was performed by members of ORNL's experimental engineering department under H. W. Savage, who reviewed and emended ORNL-1688, the report upon which this article is based.

International Neutron-Source Calibrations

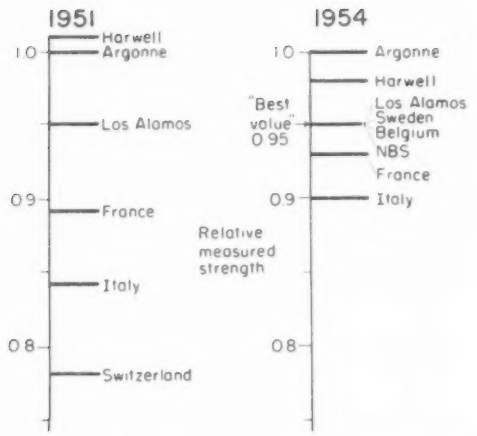

FIG. 1. Relationship among absolute neutron-source calibrations at the present time and in 1951. Chart gives source strength that would be measured at different laboratories for a particular source that measured 1 at Argonne

Progress in neutron-source standardization is reported here following visits to the major laboratories concerned

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MANY LABORATORIES have constructed and calibrated standard neutron sources, but the calibrations do not agree exactly from one laboratory to the next. A common standard at all laboratories is required in view of the importance of standard sources in quantitative measurements. Standard fluxes are needed to measure the partial cross sections of which a total cross section is composed; for example, fission or activation cross sections. Standard sources, which emit a known number of fast neutron per second, produce directly a standard fast-neutron flux. Placed inside a moderating medium, they produce an easily calculated (*1, 2*) slow-neutron flux. Portable standard sources are also of great value in determining the efficiency of health-physics instruments.

Intercalibrations of standard sources at different laboratories have revealed surprising discrepancies. In view of the unsatisfactory state of international neutron source intercalibrations, a visit* to the laboratories involved was arranged to study their calibration methods and to determine the consistency of present absolute calibrations. The principal laboratories visited and their sources and calibration procedures are listed in the table.

Only those absolute sources are listed that have been intercompared with others. Thus some earlier calibrations that cannot be compared with recent ones are omitted. In a few cases, source strengths have been corrected by the use of improved cross-section values (*3*). The errors are those quoted by the individual experimenters; the more recent calibrations have the highest claimed accuracy but probably present a more rapid improvement than is actually true.

Intercalibration of Sources

While absolute calibrations to 5% are difficult and contain many corrections, it is possible to compare two sources to 1% without great complication, particularly if their energy distributions are similar. This intercalibration may be made by slowing the neutrons in a moderator and comparing the neutron fluxes. The sources can also be accurately compared in a few minutes by measuring the neutron multiplication produced in a subcritical reactor (*4*). This method is extremely insensitive to differences in energy spectra.

Intercalibrating sources previously calibrated in individual laboratories evaluates the source calibration *methods* of the various laboratories. In the intercalibration program it is first necessary, however, to investigate the consistency of the intercalibrations themselves, even though they are much simpler than absolute measurements. If the intercalibrations form a consistent set, one obtains ratios among the absolute calibration methods in different laboratories throughout the world,

* Sponsored by the National Research Council Committee on Nuclear Science.

Standard Neutron Sources and Calibration Procedures

Laboratory	*Reference*	*Source strength, Q* (10^6 *n/sec*)	*Calibration method*
Los Alamos	(*5*)	5.9 ± 0.4	Water bath; BF_3 ionization chamber
Argonne	(*6*)	5.5 ± 0.4	Water bath with B; measure He produced by $B(n,\alpha)$
Harwell	(*7*)	9.66 ± 0.5	Reactor; compare change in k with that produced by absorber
Sweden	(*8*)	2.57 ± 0.01	Water bath; BF_3 counter and Au foils
Italy	(*9*)	3.01 ± 0.15	Water bath; Li-containing counter, Li foils
Belgium	(*10*)	15.20 ± 0.3	Water bath; Au foils
France	(*11*)	5.07 ± 0.24	Water bath; Mn foils counted in 4π counter
Switzerland	(*12*)	0.60 ± 0.05	Water bath; Mn foils
U. S. National Bureau of Standards	(*14*)	1.27 ± 0.04	Water bath; BF_3 ionization chamber

and the accuracy of the calibrations is thus assessed.

Unfortunately the intercalibrations made during past years do not form a consistent set; as a result it is necessary to eliminate some to ascertain the true relationships among the absolute calibrations. In comparing the intercalibrations it turns out that consistency is obtained if only those calibrations are used that have been repeated in several places with good agreement so that one is reasonably sure that no error has occurred in the comparison. The result of this procedure is that all sources in the table except the Swiss source can be related unambiguously.

The results of the intercalibrations today and in 1951 are presented in Fig. 1. The 1954 intercalibration signifies that a source that has strength of 1 when calibrated at Argonne would have a strength of 0.98 if measured at Harwell, 0.95 at Los Alamos, etc. The 1951 intercalibration (*1*) is presented for comparison purposes only. For convenience the Argonne source calibration was taken as 1 in Fig. 1 since, at present, it gives the highest apparent source strength.

The Los Alamos source* has been carefully compared with the Argonne source by the reactor method (*6*) so that the ratio of the Los Alamos absolute calibration to that of Argonne is well established. The Harwell source in turn was calibrated by several methods against Los Alamos source No. 40. The average of three methods with a 4% spread is used here. Thus the Harwell standardization is reasonably well related to that of Los Alamos.† The Swedish source has been calibrated against the Harwell source both in Sweden and Harwell with good agreement, so that the Swedish calibration is well fixed on the 1954 scale. The Belgian source has recently been compared to the Argonne source both in Belgium and at Argonne with consistent results. The French source was compared with the Belgian source both in Belgium and in Paris with good agreement as well.

There is a secondary check on several of the intercalibrations just mentioned because the Harwell standardization has been compared with the French standardization by means of comparison of irradiated foils at the two laboratories. This foil comparison gave a ratio of Harwell to Paris of 1.05; the figures just listed also give this ratio.

The recently calibrated NBS source (*13*) has been compared with the Los Alamos and Argonne sources with consistent results that place it in the cluster at 0.95. At first the NBS calibration emerged surprisingly low, namely 0.88, but the recent (October, 1954) final value of the Q of this source gives the excellent agreement now shown in Fig. 1.

The Italian source was compared with the French source both in Milan and Paris so the Italian standardization is well fixed on the scale of Fig. 1 relative to the French standardization. The situation is much less clear relative to the Swiss source. Its comparison to the Italian source in 1950 (giving a 0.79 value on the 1954 scale) agrees reasonably well with its comparison with the Swedish source in 1951 (a value of 0.76 resulting), the latter comparison being made both at Basel and Stockholm. However, a 1951 comparison at Harwell with the Harwell and Los Alamos sources gave a much smaller number, 0.64, for the Swiss absolute calibration. The Swiss point has not been placed on the 1954 scale because of this large discrepancy, but there is no doubt about the fact that the Swiss absolute calibration is definitely less than all others.

The improved status of international source calibration methods revealed by Fig. 1 is indeed gratifying. To some extent the present consistency of calibrations is a result of the larger scale (in time and expense) of some of the recent measurements. However, this consistency is also a measure of the understanding of the important factors in accurate standardization that has increased with the trend to high accuracy in all neutron-physics measurements.

It is possible to combine the results of the different absolute calibrations and thus improve the accuracy of the source strengths of individual standards. This procedure does not change the value of the most recent standardizations but can be considered to lower the errors somewhat. For example, omitting the Italian and Swiss results because they seem of less inherent accuracy, the others give a weighted average of 0.95 on the scale of Fig. 1, a figure that fortunately coincides exactly with four of the source calibrations, Los Alamos, Sweden, Belgium, and NBS. Thus it might be reasonable to take for the Argonne and Harwell source

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* The Los Alamos source listed in the table is their No. 44; other sources, their Nos. 40 and 70, calibrated relative to No. 44, were used in subsequent intercalibrations with sources of other laboratories, No. 70 being used for the Argonne intercomparison.

† There is evidence that Los Alamos source No. 40 is now 2% weaker relative to Los Alamos No. 44 than it was at the time of the original calibration. The change seems to have occurred about the time of the Harwell intercalibration, but there is no way to ascertain if the Harwell point should be changed by this amount. Because of the possibility of this small change and the spread in results of the three methods used at Harwell (about 4%), it is advisable to relate the Harwell calibration to the others once more by a careful source intercalibration. Any resultant change would also move the Swedish point in Fig. 1, for it is related to the others only through the Harwell calibration.

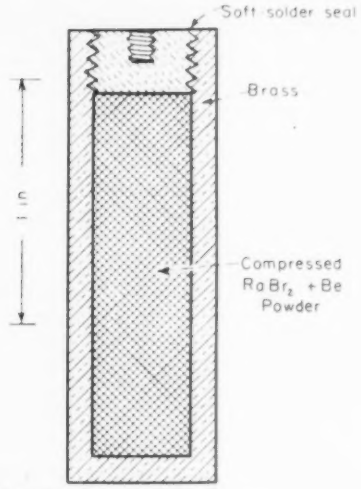

FIG. 2. Pressed Ra-α-Be source

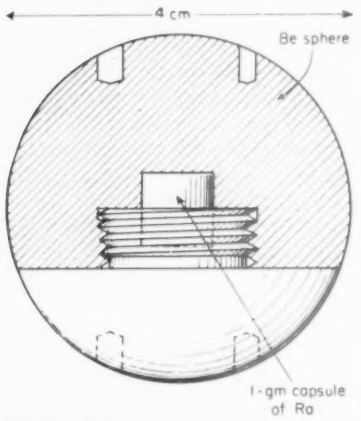

FIG. 3. NBS Ra-γ-Be photosource

Neutron-Source Preparation and Calibration

Most standard neutron sources are based on the (α,n) reaction of Be, with the α supplied by a long-lived radioelement. Figure 2 illustrates the so-called "pressed Ra-Be source" (15), made by compressing a mixture of $RaBr_2$ powder and powdered Be to maximum density. These sources produce an emission rate, Q, of about 10^7 n/sec/gm Ra. After construction, Q increases of the order of 0.5% per year because of the formation of Po^{210}. No appreciable change in emission rate resulting from shifting of ingredients is indicated by available evidence.

A photoneutron source, Fig. 3, is employed by the National Bureau of Standards. It is a Ra-γ-Be source in which the Ra α particles do not reach the Be, the neutron production resulting from the $Be^9(\gamma,n)Be^8$ reaction. A disadvantage of the Ra-γ-Be source is the much lower energy of emitted neutrons, which makes intercalibration and certain experimental uses difficult.

Absolute determination of Q for a standard source is a difficult task; up to the present time most absolute calibrations have been made to only about 5% accuracy. The absolute calibration is usually made by slowing fast neutrons emitted from the source down to thermal energy in a surrounding moderator, usually a water bath. The rate of thermal-neutron capture throughout the moderator then gives the emission rate of the source, if capture during moderation is negligible or corrected for.

The capture-rate measurement can be by various methods (16), for example by the disintegration rate in an ionization chamber containing boron or by the activation of a gold foil whose activity is subsequently measured. This measurement can be made to an accuracy of 2–3%, but other uncertainties in the complete calibration procedure, such as leakage of neutrons from the moderator, raise the final error.

Another absolute calibration method, used at Harwell, (7) makes use of a reactor. When a neutron source is momentarily inserted into a reactor it affects the reproduction factor, k, just as a neutron absorber does but in the opposite sense. By comparing the source's effect on reactor power level with that of an absorber, Q can be obtained from the capture rate in the absorber, determined by its resulting radioactivity. Because of the integrating effect of the reactor, the absorber need be at one point only, unlike the water bath method in which spatial integration is necessary.

strengths a "best value" a few per cent lower than their measured values and similarly a strength somewhat higher than stated for the French source. These changes are not very great as they are just on the edge of the experimental uncertainty of the calibration. The source strengths obtained in this way, however, can probably be considered as having an accuracy greater than that of the individual calibrations, probably of the order of 2%. This figure certainly represents a great improvement since several years ago.

All but one (the NBS) of the sources described are of the same type and all but two (Argonne and Harwell) were calibrated by closely similar methods. There are certainly other possibilities, both with regard to new types of sources as well as calibration methods, that may have superior features. At a meeting at Harwell in July 1954, new possibilities for source calibration using the photodisintegration reaction were discussed, and it now seems possible that a photosource will be calibrated in the next few years with accuracy of the order of 1%. The principle to be used is to count the photoprotons produced in the deuteron disintegration, $d(\gamma,n)p$, utilizing the 1:1 correspondence of protons to neutrons. This photoneutron source would have an energy distribution greatly different from the usual Ra-Be pressed source, however, and care would be necessary in intercalibrations in which it is involved.

* * *

It is a pleasure to acknowledge the help and hospitality received at all the European laboratories visited during the course of this investigation.

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Activation Analysis Determines Sodium Content of Aluminum Alloys

Precision better than 1%, a limiting accuracy of 0.0001%, and an average standard deviation of 0.00024% are obtained in the range 0.01–0.04% sodium when neutron-activation analysis is applied to aluminum alloys

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NEUTRON-ACTIVATION-ANALYSIS principles and techniques, as applied to determining the sodium content of aluminum alloys, are presented by this article. After outlining the procedure, details of the irradiation, chemical separation, and measurement steps are given. The precision and accuracy obtained and the problems overcome are presented.

Analysis Principles

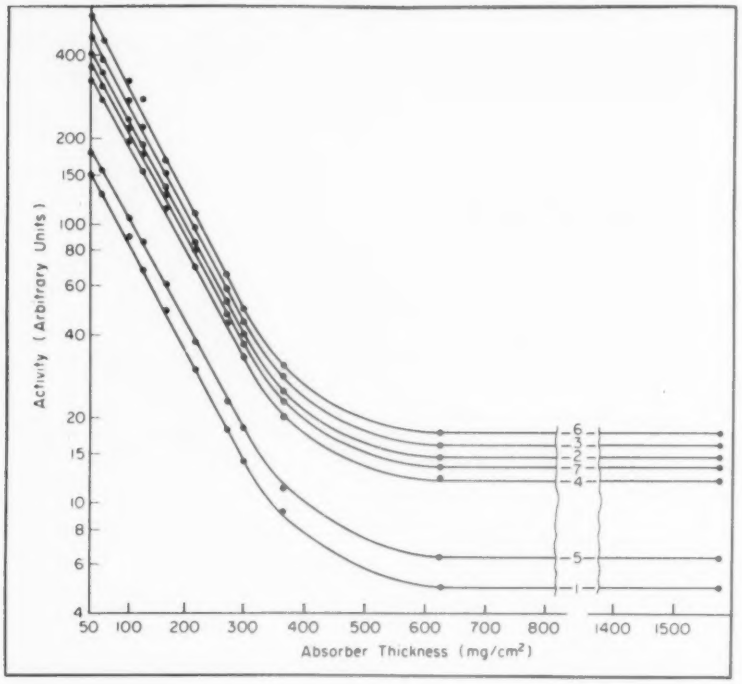
Analysis by neutron activation has been described by many authors (*1–4*). In its simplest form, it consists of exposing samples containing an unknown amount of an element together with standards containing a known amount of that element to a neutron flux and comparing the activity produced in each. In the general case a variety of radioisotopes could be produced from elements in the samples. Therefore, the radioisotopes being determined must be separated chemically. A salient feature of activation analysis is that the separation need not be quantitative but must yield a product of radiochemical purity, *i.e.*, free from other radioisotopes. A large quantity of nonradioactive carrier may be added to the irradiated material to facilitate the separation. The comparison method of activation analysis described here has a distinct advantage over many other comparison methods in that primary standards, such as pure salts, can be used.

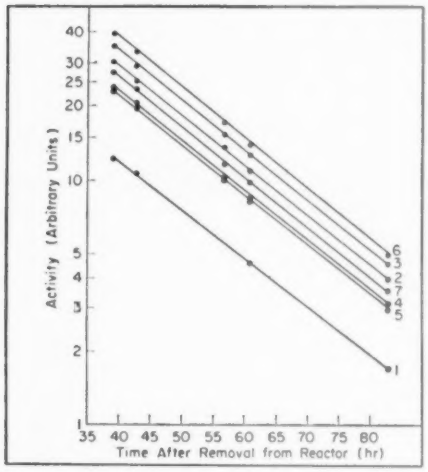
There are several possible shortcomings in activation analysis. It is generally assumed that neutron flux through reasonably sized samples is constant. However, in detailed consideration, there may be variations in neutron flux over the irradiation container dimensions from inhomogeneities in the neutron source and from attenuation of neutrons by the samples them-

Chemical Analysis Method

Determination of sodium in aluminum is customarily made by a spectrochemical comparison of samples with standards whose sodium content has been determined by a sinter-leach method (5).

Completeness of sodium removal from aluminum by the sinter-leach method has been open to question. There has been no direct proof of the validity of the chemical determination because of the difficulty of preparing synthetic metal standards of known sodium concentration and the prohibitively large blanks encountered in complete sample dissolution procedures. Neutron activation analysis appears to have sufficient sensitivity and inherent accuracy to be applied as an independent method of analysis.





DECAY (left) and absorption (above) properties of Na^{24} separated from irradiated aluminum alloys and pure sodium salts. Close correspondence (parallel to within 1%) shows effectiveness of purification procedure in eliminating all radioisotopes other than Na^{24}. Curves 1 and 2 show pure sodium salts, curves 3–7 show sodium separated from aluminum alloys. Decay measurements are followed for three sodium half-lives

selves. Similarly, the reactions having the highest cross section for thermal neutrons are of the (n,γ) type, but under actual irradiation conditions nonthermal neutrons may cause transmutation reactions [such as (n,α) and (n,p)]; producing radioisotopes of the element in question from other elements originally present in the sample.

Experimental Details

All the samples analyzed were cut from existing spectrochemical standards. One-gram disks machined from the sparking area were leached with nitric acid, then wrapped in aluminum foil for irradiation. Sodium bicarbonate and sodium carbonate (10–30 mg) were the primary standards irradiated with the alloy samples.

Packaging. Three types of packaging for the sodium salts were investigated with respect to neutron attenuation by the container. A quartz vial (1-mm wall) gave 5% lower flux than an aluminum vial. Use of Vycor resulted in a 16% lower flux on the sodium salt than did aluminum. A 2S aluminum tube 5-mm i.d. and 1-in. long, crimped at each end and cleaned with Alcoa R-5 Bright Dip (U. S. patent 2,650,157) was adopted.

Samples were irradiated in a standard aluminum irradiation can (0.75-in. i.d. × 2.875-in. long) for one week at the Oak Ridge X-10 reactor.

Irradiation conditions. Irradiation of aluminum alloys leads, in general, to the production of Na^{24} from sodium (n,γ), aluminum (n,α), and magnesium (n,p). Specific activity of the final salt is given by $(K \times \mathrm{Na} + K' \times \mathrm{Al} + K'' \times \mathrm{Mg})/(\mathrm{Na} + \text{carrier Na})$, where the K's are activation constants, and the element symbol stands for the weight of the element involved.

In the first work, the contribution of Na^{24} activity from transmutation reactions put a serious limitation on the sensitivity and precision. By activating samples of super-purity aluminum and magnesium, positions in the reactor that reduce K' and K'' to very small values were found. The apparent sodium content of the super-purity aluminum as determined after exposure in several positions was:

Reactor position	*Apparent content from Al^{27} (n,α) Na^{24} reaction*
14-A-14	0.014% Na
13-H-7	0.005% Na
14-Z-20	0.00019% Na

All further activations were carried out in positions 14-Z-19 through 14-Z-21 in which super-purity aluminum gave from 0.00014–0.00020% sodium. The lower flux in these positions (as compared to the maximum flux available in the reactor) was of no serious consequence.

After irradiating the samples, the sodium formed is chemically separated and its activity determined. The procedures for these steps will be presented after first considering the irradiation conditions in more detail. Specifically, the flux received by samples in different positions in the container will be examined.

Flux variations. Two experiments were used to detect and evaluate flux variations over the can dimensions that might occur from flux inhomogeneities in the irradiation can's immediate vicinity.

Liners of tin were placed inside the cans, the cans irradiated, and the specific activity at various points on the liner determined. There was a

maximum variation in flux of 3% from one end of the can to the other. In further experiments, quantities of sodium carbonate were irradiated in the top, middle, and bottom of a can. The specific activities obtained indicated a flux variation of less than 1%.

The most likely source of error from attenuation within the can would be self-shielding by the aluminum alloy samples. In order to determine whether or not this was an important factor, the array of disks used in an analysis was simulated by cylindrical coils of aluminum foil (0.001 in.) 2-cm in height and 1-cm in radius. The coils were irradiated and the flux variation within them determined by counting ¼-in. circles punched from various positions along a radius. The variation with radius at half the height of the coil was about 5%/cm.

From the foregoing variations, it can be shown that the average flux on a disk in the middle of the cylinder differs from the average flux on a disk at the end of the cylinder by less than 1%.

Sodium separation. Aliquots from the Na_2CO_3 and $NaHCO_3$ standards are carried through a process identical to the following one for obtaining radiochemically pure sodium from the irradiated aluminum alloys. The alloy is dissolved with HCl and H_2O_2 in the presence of 5-mg of carrier Na (as NaCl). The residue after the high-silicon alloys are dissolved is collected and the Si volatilized as SiF_4. The remaining residue is then dissolved and added to the HCl solution. Precipitation of the Na as sodium zinc uranyl acetate follows. The precipitate is filtered, then redissolved in hot water. As a general clean-up, heavy metals are then precipitated as sulfides. This step also eliminates the possibility of Zn contamination by exchange with the reagent, or Cu contamination by co-precipitation. The sodium is re-precipitated, and the resulting salt is used directly for the counting measurements. The figures on page 30 show the effectiveness of the purification procedure.

Activity determination. The counting measurements were carried out using an end-window Geiger tube. Enough counts were taken to obtain less than 1% statistical error. To eliminate self-absorption errors, all β radiation was filtered out with a 600 mg/cm² Al filter and only γ rays were counted. To eliminate backscattering errors, the samples were counted in identical containers. Counting measurements were made at rates no higher than 10,000 counts per minute, and experimentally determined coincidence corrections were applied.

The activity from the uranium in the sodium zinc uranyl acetate salt, equivalent to about 0.0003% sodium, was determined by means of a blank and corrected for. The relative activities of the primary standards and the unknown samples were read from the decay curves at a particular time.

Results and Conclusions

Since in positions 14-Z-19 through 14-Z-21, the super-purity aluminum gave from 0.0001 to 0.0002% sodium, the blank resulting from the transmutation reaction can be no larger than about 0.0002%. Conversely, the sodium content of that sample is between the limits 0.0000 and 0.0002% but is indeterminate. A correction of about 0.0001% (½ the observed blank) was made in each set of determinations. The uncertainty in the blank results in a limiting accuracy of ±0.0001% sodium.

Precision and accuracy of method. In the table, the results of several analyses are given. Many analyses were performed in multiplicate. In the range below 0.01% sodium, the average standard deviation was 0.00009%; from 0.01–0.02% sodium, the average standard deviation was 0.00020%; and from 0.02–0.04% sodium it was 0.00042%. It is apparent from the observed precision that random errors that might be associated with variation in flux over the can dimensions, or with self-shielding by the aluminum alloy samples, and statistical errors associated with the counting measurements, did not exceed 1%.

It is seen from the table that activation analysis gives results in excellent agreement with the previously assigned values for the standards. The technique of activation analysis appears to be capable of producing sufficiently precise and accurate results to be useful not only for directly calibrating primary analytical standards but for general application as an umpire-grade method in cases where requirements of sensitivity or limitations in form or size of sample preclude other methods.

Sodium Content of Aluminum Alloys

Aluminum Alloy	*Previously assigned % sodium*	*Neutron activation % sodium*	*Number of determinations*	*Standard deviation (%)*
3A	0.0014	0.0017	2	0.00007
	0.002	0.0024	4	0.00016
	0.008	0.0107	2	0.00000
	0.0006	0.0007	1	—
	0.005	0.0064	2	0.00010
	0.032	0.0352	4	0.00083
	0.018	0.0199	2	0.00000
	0.023	0.0267	2	0.00007
	0.016	0.0189	2	0.00016
7.5% Si	0.002	0.0015	1	—
	0.032	0.0307	2	0.00000
220	0.001	0.0005	2	0.00000
	0.006	0.0061	2	0.00007
	0.011	0.0125	2	0.00045
	0.026	0.0265	4	0.00040
2024	0.017	0.0168	4	0.00025
	0.013	0.0130	2	0.00040
	0.006	0.0063	2	0.00010
	0.0025	0.0027	2	0.00000
7075	0.006	0.0054	2	0.00016

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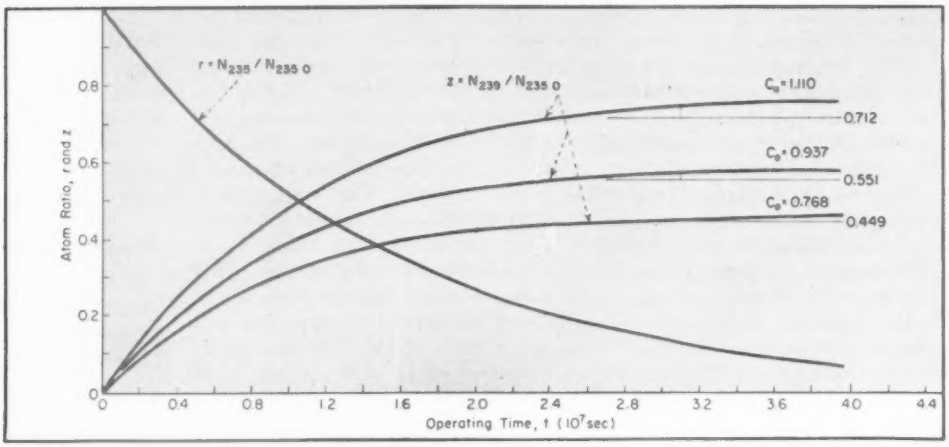

FIG. 1. Plutonium production and uranium depletion

Producing Plutonium in U-D_2O Reactors

Cost of nuclear power from dual-purpose reactors depends on the production rate of plutonium as well as on its price. How conversion ratios and multiplication factors vary in infinite, bare, reflected, and enriched lattices is shown here

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FOR HEAVY-WATER REACTORS, this article investigates the plutonium production rate and reactivity behavior during reasonably long running periods. Effect of fuel enrichment is considered.

The conversion ratio, that is, the number of plutonium atoms formed per U^{235} atom used, is

$$C = \nu\epsilon\frac{\sigma_{f235}N_{235}}{\sigma_{a235}N_{235}}l_{fst}(1-p) + \frac{\sigma_{a238}N_{238}}{\sigma_{a235}N_{235}} \quad (1)$$

Its initial value is characteristic for a given reactor. Using the proper constants, i.e., the values of the constants averaged over the region of thermal-neutron energies, the initial ratio in natural-uranium systems is

$$C_0 = 2.11\epsilon\, l_{fst}(1-p) + 0.599 \quad (2)$$

Three cases will be considered here: 1, when $C_0 = 0.768$; 2, when $C_0 = 0.937$; and 3, when $C_0 = 1.11$.

A limiting value of C_0 is obtained when no neutrons are lost due to leakage or to absorption in structural materials and moderator. As in this case, $l_{fst} = l_{th} = f = 1$, while $\epsilon = 1.03$ is a reasonable value, and $\eta = 1.32$, it follows from the condition that $k_{eff} = 1$ that $p = 0.735$. The limiting value of C_0, i.e., the value of C_0 in infinite natural-uranium lattices, is 1.17.

Infinite System

An understanding of the conversion behavior of an infinite reactor that uses natural-uranium fuel provides a basis for consideration of finite reactors—including those using enriched fuel.

U^{235} disappearance. The reactor flux is kept constant, thus the decrease in number of U^{235} atoms is

$$r = e^{-\sigma_{a235}\phi t} \quad (3)$$

Plutonium production. The total number of Pu atoms formed per second per initial U^{235} atom, i.e., those formed by resonance capture plus those formed by thermal capture, is

$$F = \phi(\sigma_{f235}r\nu_{235} + \sigma_{f239}z\nu_{239})\epsilon\, l_{fst}(1-p) + \sigma_{a238}\phi N_{238}/N_{235\,0} \quad (4)$$

The number of Pu atoms present per initial U^{235} atom is governed by

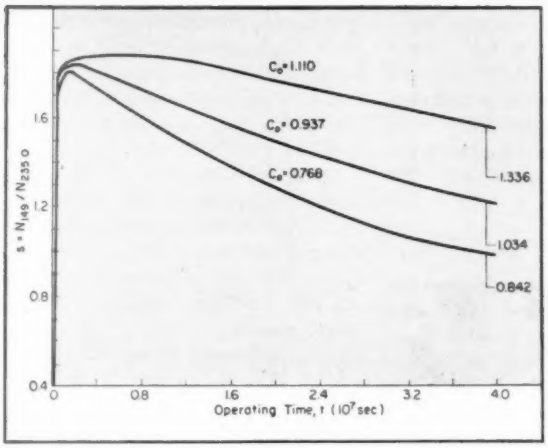

FIG. 2. Samarium-149 concentration

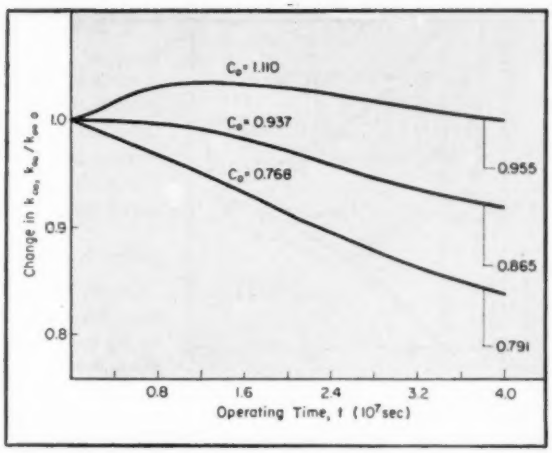

FIG. 3. Change in k_∞

$$F - \sigma_{a239}\phi = dz/dt \qquad (5)$$

Both r and z are plotted in Fig. 1 for the three cases considered; z and r are actually functions of ϕt.

Samarium poisoning. Samarium concentration, shown in Fig. 2 as a function of time, follows from

$$ds/dt = \Gamma r\sigma_{f238}\phi + \Gamma z\sigma_{f239}\phi - \sigma_{a149}s\phi \qquad (6)$$

The fact that the curve flattens after a short and very sharp rise is due to the large destruction rate of Sm^{149}.

Variation in k_∞. In discussing converter and breeder properties, it is interesting to note the system's reactivity change due to loss of U^{238} atoms, gain in Pu atoms, and production of Sm^{149} poison. Of the factors constituting the infinite multiplication factor, $k_\infty = \eta\epsilon pf$, only f and η are considered sensitive to changes in fuel composition; ϵ and p will remain practically constant as long as the number of U^{238} atoms is constant.

The variation of η can be calculated directly from Fig. 2 together with pertinent cross sections. Calculation of the variation in f is straightforward but rather cumbersome. The well-known formulas for f can be applied, and the variation in fuel composition can be taken into account (*3, 4*). The size of the unit cell is derived from the value of p chosen for a particular C_0. The functions $k_\infty/k_{\infty 0}$ are plotted against time in Fig. 3.

U^{238} used. The accuracy of the assumption that the number of U^{238} atoms remains constant during long periods can be checked easily by calculating the number of U^{235} atoms used during reactor operation. As a function of time, the total number of U^{238} atoms that disappear follows from Eq. 5, and is

$$T_{238} = \int_0^t F\,dt = z(t) + \sigma_{a239}\phi \int_0^t z\,dt \qquad (7)$$

This function is plotted in Fig. 4. The number of U^{238} atoms that disappear by fast fission is small (~4%) compared to the atoms disappearing by resonance and thermal-neutron capture.

Conclusions. The conversion ratio C varies with time. The "asymptotic" number of Pu atoms (i.e., if conversion could go on indefinitely without the

Assumptions

A rigorous investigation of conversion would be very complicated, thus the following simplifying assumptions (1) are made: 1, Pu^{239} is formed directly from U^{238}; 2, ϵ, l_{fst}, and p are constant with time; 3, number of U^{238} atoms is constant; 4, Sm^{149} is the only serious poison produced ($\sigma_{a149} = 46{,}000$), and capture of one neutron transforms it into Sm^{150}, which has a negligible cross section; 5, poisoning by Xe^{135} is a nonvariable effect because the average flux throughout the reactor is constant with time (2), and thus loss in system reactivity due to Xe poisoning is accounted for by using a proper k_{eff} value at $t = 0$; 6, change in reactivity during conversion is made up for by cadmium-plate control so that the reactor is kept running at equilibrium (this means actually that l_{th} is adjusted so that k_{eff} remains equal to 1); 7, average flux is constant at 10^{14} n/cm²/sec; 8, plutonium is formed uniformly over the circular cross section perpendicular to the fuel rod's axis; 9, unit cell is cylindrical in shape, and consists of a single bare uranium-metal rod of radius a = 1.27 cm in heavy water, and omission of rod canning does not affect the change in f during the process; 10, when $C_0 = 0.768$, 0.937, or 1.11, the radius of the unit cell is 7.90, 5.52, or 4.49 cm, respectively; 11, for the finite reactors, spherical geometry has been chosen; 12, in cases where graphite reflectors are applied, they are considered to be infinitely thick.

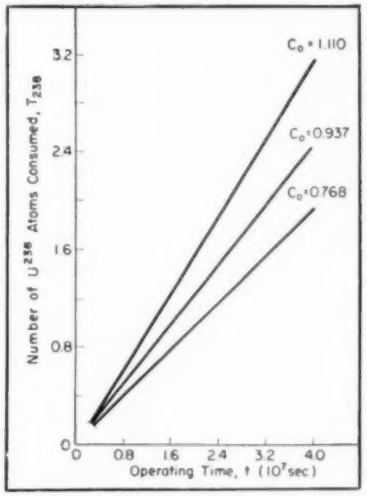

FIG. 4. Total U^{235} consumption

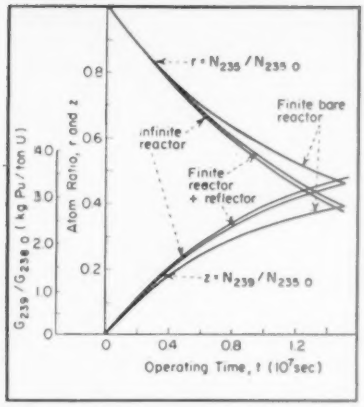

FIG. 5. Plutonium concentration and uranium depletion, $C_0 = 0.937$

amount of U^{238} atoms decreasing) can be expressed by $z_{asymp} = 0.412/(1.685 - C_0)$, which actually indicates roughly the maximum obtainable z, which is slightly more than the asymptotic value shown in Fig. 1.

The limiting value of C_0 is about 1.17. As shown in Fig. 3, a reactor having $C_0 < 1.1$ can have sufficiently good converter properties to have a large part of the U^{238} burnt up before the system's reactivity drops too far.

It must be emphasized that all products of neutron nonfission capture have been neglected. For instance, from the figures it is seen that in the case where $C_0 = 1.11$ at $t = 4 \times 10^7$ sec, about 0.75 Pu atoms are present per initial U^{235} atom, while the total number of Pu atoms that were once formed but have since disappeared is 3.15. This means that $2.4\ (\sigma_{f239}/\sigma_{a239}) \approx 1.55$ Pu^{239} atoms underwent fission; $2.4(\sigma_{a239} - \sigma_{f239})/\sigma_{a239} \approx 0.85$ Pu^{239} atoms transformed into Pu^{240} have been completely neglected as far as their contribution to poison or total fission cross section goes. The same applies to the $0.93(\sigma_{a235} - \sigma_{f235})/\sigma_{a235} = 0.14$ U^{236} atoms formed.

Finite Systems

Plutonium production, poison formation, uranium consumption and change in k_∞ have been shown to be uniform throughout the volume of an infinite system. But the flux distribution is curved in a finite reactor, and these quantities are functions of space as well as time. The systems considered here are a bare spherical pile and a spherical pile with an infinite graphite reflector. Both systems have $k_{eff\,0} = 1.06$ and $C_0 = 0.937$.

It is assumed that the neutron distribution is constant with time. Instead of the quantity z, now the total amount of Pu present per unit of natural uranium will be given and compared with the corresponding quantity in the case of an infinite reactor.

Applying the usual expression for the flux in spherical reactors and choosing $\phi_{avg} = 10^{14}$, the plutonium concentration, $z[\phi(R)t]$, at any time and place in the reactor can be derived from Fig. 1.

The total amount of Pu present in the reactor at the time t, divided by the amount of natural uranium initially present, is

$$G_{239}/G_{238\,0} = (239/238)(1/140)z_{avg} = (239/238)(1/140)(1/V)\int z\,4\pi R^2\,dR \quad (8)$$

The flux distribution is assumed to remain constant with time; δk_{eff} can be found from the change in the local k_∞ and in $N_a\sigma_a$, together with the unperturbed flux distribution in the reactor, $\phi(R)$, by Eq. 13.15.3 in ref. (4).

Some simplifications can be made. The diffusion coefficient, D, is relatively insensitive to fuel-composition changes such as result from uranium fission and plutonium formation. In one-group diffusion theory, v is constant, and $k_{eff} = k_\infty l_{th}$. The expression for the change in reactivity is

$$\delta k_{eff} = l_{th}\{\int_V \delta k_\infty \phi^2\,dV/\int_V \phi^2\,dV + [(k_\infty - 1)/(1 - f)]\int_V \delta f \phi^2\,dV)/\int_V \phi^2\,dV)\} \quad (9)$$

The first part gives the change in reactivity of the finite systems due to the change in k_∞, the second part accounts for the effect of the change in the diffusion length in the reactor, and thus for the leakage change.

Bare pile. For the given unit-cell geometry, a bare spherical reactor of radius $R_0 = 200$ cm would have $k_{eff\,0} = 1.058$, and $\phi_{avg} = 10^{14}/cm^2/sec$. By use of the curve $z(\phi t)$, given as Fig. 1, the amount of plutonium present relative to the initial amount of natural uranium has been calculated by Eq. 8 and is shown in Fig. 5.

The effect of Pu production, U^{235} consumption, and Sm^{149} formation on k_{eff} has been calculated using Eq. 9 and the curve $C_0 = 0.937$ in Fig. 3. The function $k_{eff}/k_{eff\,0}$ is shown in Fig. 6 for the finite reactor and for the corresponding infinite reactor.

Reflected spherical pile. The spherical pile is surrounded by an infi-

Symbols

C = conversion ratio = Pu atoms formed per U^{235} atom used up
F = Pu atoms formed per sec per initial U^{235} atom
f = thermal utilization = slow neutrons absorbed in fuel per total slow neutrons absorbed
G = total amount of isotope present
k = multiplication factor = slow neutrons in one generation per slow neutron in preceding generation
l = nonleakage factor
N = atoms/cm³
p = resonance escape probability = fraction of fast neutrons that escape capture while slowing
R = reactor radius
$r = N_{235}/N_{235\,0}$
$s = N_{149}/N_{235\,0}$
T = total atoms that disappear
t = time of operation, sec
V = reactor volume
$z = N_{239}/N_{235\,0}$
$139 = N_{238\,0}/N_{235\,0}$
α = enrichment factor = $139(N_{235}/N_{238}) - 1$
Γ = relative Sm^{149} yield in U^{235} and Pu^{239} fissions = 1.3%
ϵ = fast fission factor = ratio of neutrons produced by all-energy neutron fissions to those from slow-neutron fissions
η = neutrons emitted per slow-neutron capture in fuel
ν = neutrons produced per slow-neutron fission
σ = cross section, barns, 10^{-24} cm²
ϕ = slow-neutron flux, no./cm² sec

Subscript	*Pertains to*
0	initial value
149	Sm^{149}
235	U^{235}
238	U^{238}
239	Pu^{239}
∞	infinite lattice
eff	finite lattice
fst	fast neutrons
th	thermal (slow) neutrons
c	critical value
f	fission
a	absorption
avg	average

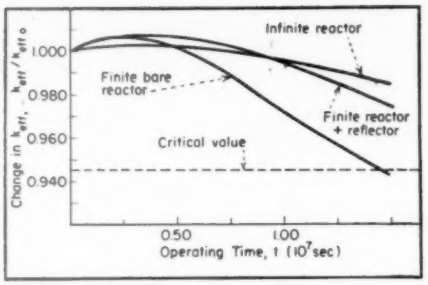

FIG. 6. Variation in k_{eff}

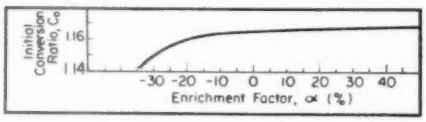

FIG. 7. Limiting value of initial conversion ratio as function of fuel enrichment

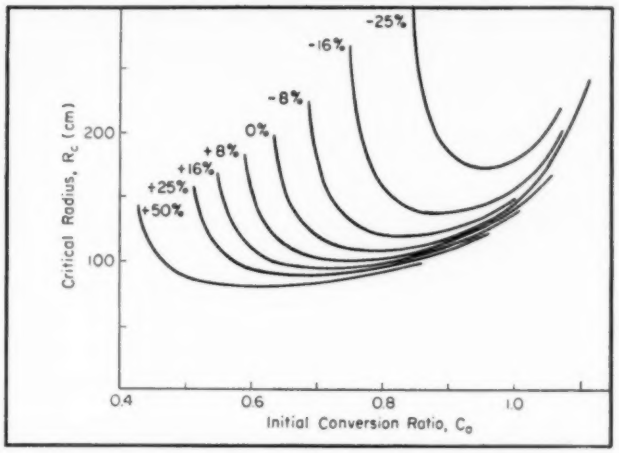

FIG. 8. Critical radius of bare reactor as function of initial conversion ratio for various enrichments

nite graphite reflector; thus its core is reduced to 162.2 cm to keep the value of $k_{eff\,0}$ unchanged. The quantities z_{av_8} and $G_{239}/G_{238\,0}$ have been calculated as described in the preceding paragraphs, and the results are plotted in Fig. 5. The quantity $k_{eff}/k_{eff\,0}$ is plotted in Fig. 6.

Conclusion. By proper replacement of the outer region of a bare reactor by a reflector, a reactor system of the same buckling can be obtained. If the central flux is kept unchanged, the core's average flux is higher in the reflected system than in the bare one. Thus, if the average flux is kept constant, it is obvious that the central flux is higher in the bare reactor than in the reflected one.

As the influence of a perturbation is proportional to the square of the local flux, the bare reactor is bound to be more sensitive to changes in k_∞.

Figure 6 shows that the curves representing $k_{eff}/k_{eff\,0}$ intersect. The initial rise is faster in the bare reactor. Apart from the effect of δk_∞ on δk_{eff}, in finite reactors there is, especially at the beginning, a definite effect due to the decrease in neutron leakage. When $C_0 = 0.937$, f has a maximum at $t \approx 10^7$ sec, and δf remains positive up to $t \approx 4 \times 10^7$ sec. Since thermal-neutron leakage decreases as thermal utilization increases, the extra gain in k_{eff} in the finite reactors (as compared with an infinite reactor) is due to the decrease of thermal-neutron leakage. However, at longer running periods the effect due to the change in k_∞ becomes predominant.

As the flux at a given distance from the center is higher in the bare reactor than in the reflected reactor, the function $k_{eff}/k_{eff\,0}$ will drop, in the long run, faster in the former case than in the latter. In practical cases, k_∞ always will tend to drop below $k_{\infty\,0}$ after a certain running period. Thus it seems advantageous to arrange the fuel rods nonuniformly so as to render the flux distribution as flat as possible.

Enriched Systems

Equation 1's definition of the initial conversion ratio shows that C_0 is a function of the isotopic ratio between U^{238} and U^{235}. The quantities l_{fst}, p, and η are also functions of this isotopic ratio. Thus the value of C_0 under the condition $k_{eff\,0} = 1$ is a rather complicated function of the fuel composition.

This section investigates the limiting value of C_0 (in infinite systems) as a function of moderate enrichment as well as of the effect of such enrichment on the critical size of a bare spherical reactor at a fixed value of C_0. For convenience, the enrichment factor, α, has been defined so that for a given value of α, $N_{235}/N_{238} = (1 + \alpha)/139$. Values of α in the range from -35% to $+50\%$ have been chosen for this study.

Initial conversion ratio. The limiting value of C_0 can be computed easily when the radius of the unit cell for which $k_\infty = 1$ has been found. Figure 7 shows $C_{0\,max}$ as a function of enrichment. In the region of the chosen values the variation of the limiting value of C_0 is small.

Critical radius. Enrichment's effect on the critical size of a reactor for a fixed value of the initial conversion ratio can be shown easily. The critical radius, R_c, as well as C_0, can be computed for any value of the radius of the unit cell. A combination of these data yields a relation between R_c and C_0. This is shown in Fig. 8.

Discussion. The variation of the isotopic ratio N_{238}/N_{235} in the range from 93 to 214 does not strongly affect the limiting value of C_0 of a reactor. Although an increase of the isotopic ratio causes an increase of the second part of the right-hand side of Eq. 2, the criticality condition for an infinite system $k_\infty = 1$ sets an increased lower limit for p, which causes a decrease in the first part of the right-hand side of Eq. 2. These two effects nearly balance each other completely in the region of enrichment considered.

However, enrichment does affect the critical size of a reactor of given C_0 considerably. An increased lower limit of p means that the unit cell radius must be increased. The value of the thermal utilization will drop, thus $(1 - f)$ will rise, and the leakage out of the reactor will increase considerably. These effects must be offset by increasing reactor size.

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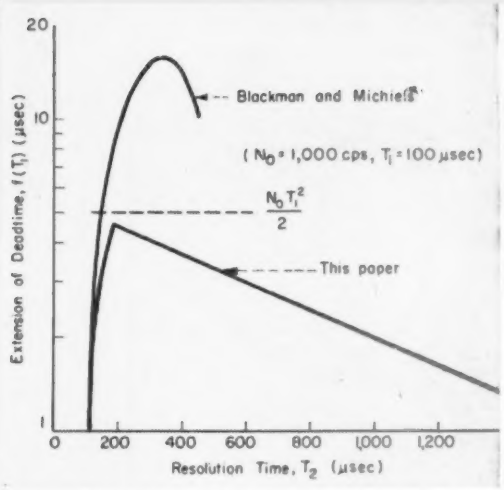

FIG. 1. Theoretical extension of deadtime, $f(T_1)$, for Type II-Class B circuit

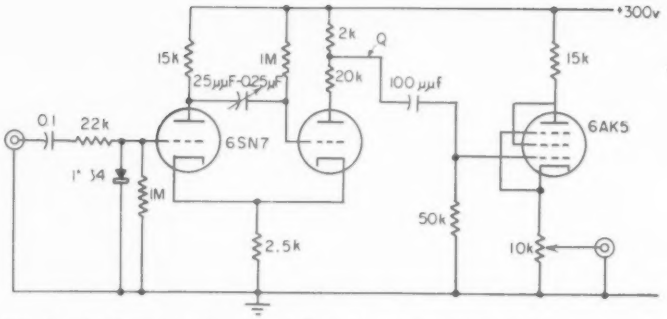

FIG. 2. Univibrator having Type II-Class B resolution characteristics

Resolution Losses in Counters and Trigger Circuits

A theory of counting losses due to finite resolving time is verified. Trigger circuits can compensate nonideal resolution characteristics of G-M counters

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University of Arkansas
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COUNTING LOSSES due to the finite resolving time of nuclear detection equipment can be quite significant. These losses can be calculated, at least in certain ideal cases, if pertinent characteristics of the detector and associated electronic equipment are known.

Blackman and Michiels (*1*) have reviewed the theory of resolution losses. They point out that, until 1948, only the expression derived by Ruark and Brammer (*2*) for Type I circuits (can be re-excited during recovery) had been satisfactorily confirmed experimentally (*3*).

In 1950 Collinge (*4*) studied resolution losses in Type II circuits (cannot be re-excited during recovery). He varied the precalibrated quench time of a quench multivibrator at various input counting rates. Agreement with theory was within 1% up to 40% counting loss but increased rapidly for greater losses. This, Collinge suspected, was due to a factor not accounted for by the theory: the decrease in the resolving time of the quench multivibrator as the on/off ratio of the circuit increased. This phenomenon, characteristic of many electronic circuits, can also be observed in Geiger counters (*5*, *6*).

This article extends examination of random input resolution losses for a Type II-Class A circuit, especially in the region of large losses. A study will also be made of random-input resolution losses for Geiger tubes in series with a stable Type II circuit.

Counting-Loss Theory

Consider a detector through which particles are passing at a rate N_0. If the probability of occurrence of any particle during a time Δt is causally independent of the occurrence of a previous particle and depends only on the product of N_0 and Δt, the particles are said to be randomly distributed in time. The probability $P_t(k)$ of observing k causally independent particles in time t, when the total rate of occurrence is N_0, is given by Poisson's equation

$$P_t(k) = \frac{e^{-N_0 t}(N_0 t)^k}{k!} \qquad (1)$$

Experimental confirmation of this relationship will be given later in this article.

A Type II-Class B detector or circuit is insensitive for a time T following the counting of each pulse. Therefore, an average of N_0T pulses are rejected for every pulse counted, and the efficiency of the device is

$$\frac{N}{N_0} = \frac{1}{1 + N_0 T} \qquad (2)$$

If there are two Type II-Class B circuits in series, we must consider three separate cases. The output of the first detector of deadtime T_1 will be given as N_1 and the output of the second detector of deadtime T_2 will be given as N_2.

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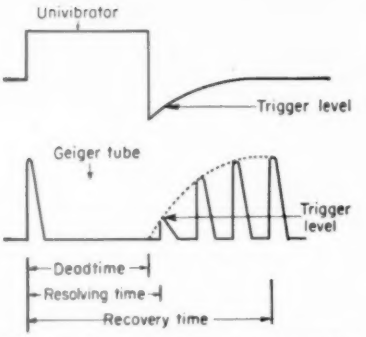

FIG. 3. Illustrating the similar resolution characteristics of Geiger counters and trigger circuits

Case 1, $T_1 \geqq T_2$. In this case the second circuit is never called upon to count pulses that it cannot resolve. The total deadtime of the series combination is $\sigma = T_1$ so that this reduces to the single circuit case and

$$N_2 = N_1 = \frac{N_0}{1 + N_0 T_1} \qquad (3)$$

Thus a series of circuits following one whose deadtime exceeds that of each of the rest can be considered mathematically as a single circuit.

Case 2, $T_1 < T_2 \leqq 2T_1$. In this case the total average deadtime of the combination is greater than T_2 because circuit 1 may be reactivated while circuit 2 is dead and remain insensitive to another event for a time after circuit 2 is capable of reactivation. Thus on the average there will be an extension, $f(T_1)$, of the deadtime that must be added to T_2 to give the total average deadtime of the series combination

$$\sigma = T_2 + f(T_1) \qquad (4)$$

For circuit 1 to be reactivated during a time interval dt at time t after recovery, it must not have been activated from $t = 0$ to t and then be activated during dt. From Eq. 1 the probability of no activation in time t is

$$P_t(0) = \frac{e^{-N_0 t}}{0!}(N_0 t)^0 = e^{-N_0 t} \qquad (5)$$

The probability of excitation during dt is $N_0 dt$. The product of the two separate probabilities is P_r, the probability of reactivation during, but not before, t to $t + dt$; thus

$$P_r = N_0 e^{-N_0 t} dt \qquad (6)$$

Any such reactivation during $(T_2 - T_1)$ will result in an extension of the deadtime. The total probability, P_E, of this occurring can be expressed as the complement of the probability of no reactivation during $(T_2 - T_1)$

$$P_E = 1 - e^{-N_0(T_2 - T_1)} \qquad (7)$$

The average time at which an extension is caused is

$$t_a = \frac{1}{P_E} \sum_{0}^{(T_2 - T_1)} t P_r = \frac{1}{P_E} \int_0^{(T_2 - T_1)} N_0 t e^{-N_0 t} dt \qquad (8)$$

Integrating by parts

$$t_a = \frac{1}{N_0} - \frac{(T_2 - T_1)e^{-N_0(T_2 - T_1)}}{1 - e^{-N_0(T_2 - T_1)}} \qquad (9)$$

Because we are measuring time from the recovery of circuit 1, if reactivation takes place at time t the extension of deadtime will be

$$T_E = 2T_1 + t - T_2 \qquad (10)$$

The average extension, T_E, will then be, from Eqs. 9 and 10

$$T_E = \left(T_1 + \frac{1}{N_0}\right) - \frac{(T_2 - T_1)e^{-N_0(T_2 - T_1)}}{[1 - e^{-N_0(T_2 - T_1)}]} - (T_2 - T_1) \qquad (11)$$

The average increase in deadtime, $f(T_1)$, is then the product $P_E \times T_E$, that is

$$f(T_1) = \left[T_1 + \frac{1}{N_0}\right][1 - e^{-N_0(T_2 - T_1)}] - (T_2 - T_1) \qquad (12)$$

An approximate equation is obtained by expanding the exponential and dropping all cubic or higher-order terms

$$f(T_1) = (N_0/2)(3T_1 - T_2)(T_2 - T_1) \qquad (13)$$

Case 3, $T_2 > 2T_1$. The procedure for this case is the same, but the limits of integration are different. Events occurring anywhere within a time T_1 preceding t now affect the probability of extension.* One obtains

$$f(T_1) = [N_0^{-1}(e^{N_0 T_1} - 1) - T_1]e^{-N_0(T_2 - T_1)} \qquad (14)$$

Dropping higher-order terms as before

$$f(T_1) = \tfrac{1}{2} N_0 T_1^2 \qquad (15)$$

The total deadtime is approximately

$$\sigma = T_2 + \tfrac{1}{2} N_0 T_1^2 \qquad (16)$$

Driscoll (*9*) has given the same approximate equation without publishing the derivation. It can readily be seen that this relationship gives the maximum deadtime for a series combination and thus is very useful.

Using a different statistical treatment, Blackman and Michiels (*1*) derived an expression for the counting efficiency, E, of a series combination of deadtimes

$$E \equiv N_2/N_0 = \frac{[1 - N_0(T_2 - T_1)e^{-N_0(T_2 - T_1)}]}{(1 + N_0 T_1)} \qquad (17)$$

Their equation predicts greater resolution losses than ours, as can be seen from Fig. 1.

Glossary

Deadtime—*Time interval after pulse has occurred during which counter is insensitive to further ionizing events.* (*2, 7*)

Resolving time—*Minimum time interval by which two pulses must be separated to be detected as separate pulses by counter and its accessories.*

Recovery time—*Time interval that must elapse after pulse has occurred before full-size pulse can again occur.*

Types of Circuits

Type I—*Can be re-excited during recovery (e.g., Cenco-type register).*

Type II—*Cannot be re-excited during recovery.*

Class A—*Resolving time depends on counting rate.*

Class B—*Resolving time is independent of counting rate.*

A Geiger counter has a deadtime during which it is essentially insensitive, followed by a recovery time during which it can be re-excited, see Fig. 3. The resolving time is dependent upon the counting rate (6). Thus, a Geiger counter is a Type I + II-Class A circuit.

Instrumentation

The simple cathode-coupled-pair trigger circuit shown in Fig. 2 has a

* This is adequate for the purpose, but not strictly correct. Events occurring at any time from $t = 0$ to t must be considered for a rigorous derivation.

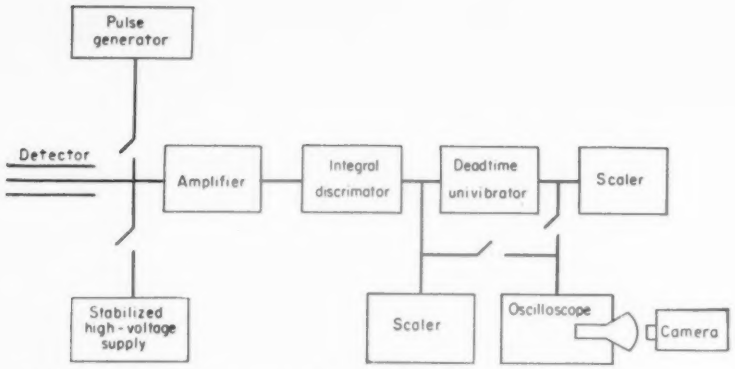

FIG. 4. Instrumentation for study of resolution loss

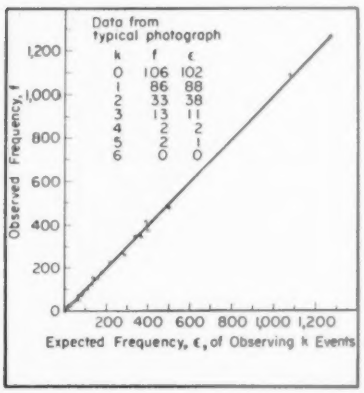

FIG. 5. Experimental verification of randomness. Predicted values, ε, from Eq. 1

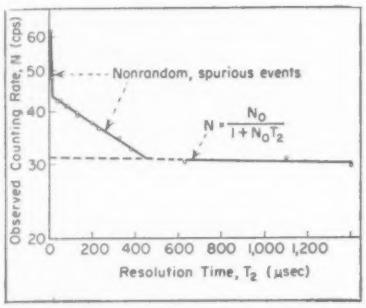

FIG. 6. Distribution of spurious counts from high-gas-gain proportional counter irradiated by γ rays shows ($T_2 < 20$ μsec) effect of counts from photoelectrons from cathode and ($T_2 < 500$ μsec) those due to ions, followed by region obeying Eq. 3

ANOTHER APPROACH:

Empirical Correction for Resolution Loss

This article seeks an understanding of resolution losses based on an investigation of the parameters directly responsible for those losses. Empirical approaches are also possible. For example, there is the method of paired sources: two radioactive sources are counted separately and then together, counting geometry being kept constant. The combined counting rate will be less than the sum of the individual rates, due to resolution losses that can be measured and therefore compensated. Kohman (8) has extended this method using several sets of pairs to evaluate parameters in a power-series approximation for the true counting rate.

One of the authors of this paper has determined resolution losses by use of short-lived radioactivity of known half-life. If losses are significant the semilog plot will be nonlinear, and resolution corrections at various counting rates thus can be determined.

recovery time that is independent of input pulse rate under certain operating conditions. When triggered by 0.4-μsec-duration pulses with amplitude varying from 0.3 to 10 volts, no variation in recovery time was observed up to 2×10^5 input pulses per second. The pulse at Q (Fig. 2) before differentiating is shown in Fig. 3. The resolving time is dependent upon input pulse height, but the circuit cannot be retriggered during the deadtime. For input pulses of constant height, it may be treated mathematically as a Type II-Class B circuit. Figure 3 shows that the behavior of this trigger circuit is analogous to that of a Geiger tube.

If the grid of the "on" triode is returned to cathode instead of B^+, the recovery time becomes highly dependent on input pulse rate. This is also true for inadequate d-c-restoration of the input grid. Under these conditions, the decrease in recovery time with increased input pulse rate is very similar to the familiar phenomenon observed in Geiger tubes. If the input pulse height to this circuit is now made variable, the analogy to the Geiger tube is almost perfect. The circuit can then be described as Type I + II-Class A.

Instrumentation used for these counting experiments is diagrammed in Fig. 4. The detector could be operated either in the proportional or Geiger region. The amplifier and integral discriminator were of the type described by Jordan and Bell (*10*). The resolution time of the integral discriminator was less than 5 μsec. Output and input of the variable deadtime circuit were monitored by scalers or by cathode-ray oscilloscope and camera. A calibrated pulse generator was used to check system performance and to calibrate the deadtime circuit. The cathode-ray-oscilloscope sweep was also calibrated.

To determine the resolving time of the deadtime circuit, the frequency of the pulses from the pulse generator was increased until the circuit began to "count down," as observed by the counting rate of the output scaler or the oscilloscope. For Geiger counting, integral-discriminator resolution time could be neglected, but it limits resolution for proportional counting.

Experiments and Results

We first investigated the fundamental randomness assumption. Resolution loss was then measured as a function of circuit resolving time for the Type II-Class B univibrator and for a Geiger counter.

In the absence of nuclear complexity, experiments (*11, 12, 13*) prove the random nature of radioactive decay. However, the output of a particular detector may be nonrandom because of its finite resolution time and the presence of spurious counts. Spurious events caused by delayed arrival of negative ions at the anode, and by positive ions at the cathode, have been observed in Geiger counters (*14, 15*). In proportional counters, spurious events may also result from delayed

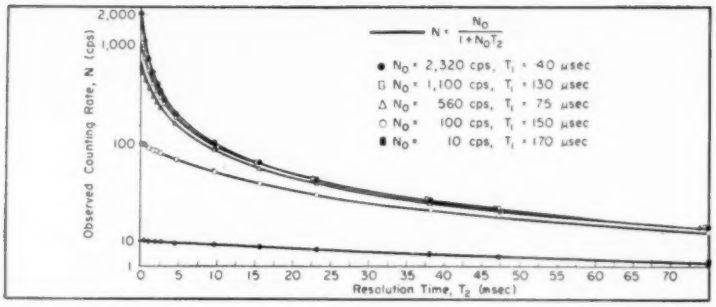
$N = \frac{N_0}{1+N_0T_2}$
● N_0 = 2,320 cps, T_1 = 40 μsec
□ N_0 = 1,100 cps, T_1 = 130 μsec
Δ N_0 = 560 cps, T_1 = 75 μsec
○ N_0 = 100 cps, T_1 = 150 μsec
■ N_0 = 10 cps, T_1 = 170 μsec
Observed Counting Rate, N (cps)
2,000
1,000
100
10
1
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
Resolution Time, T_2 (msec)

FIG. 7. Resolution loss when $T_2 \gg T_1$

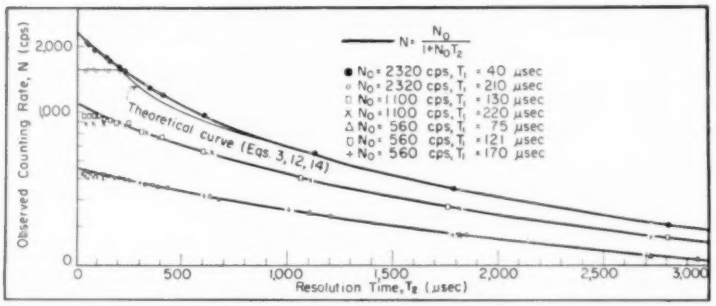
$N = \frac{N_0}{1+N_0T_2}$
● N_0 = 2320 cps, T_1 = 40 μsec
○ N_0 = 2320 cps, T_1 = 210 μsec
□ N_0 = 1100 cps, T_1 = 130 μsec
× N_0 = 1100 cps, T_1 = 220 μsec
Δ N_0 = 560 cps, T_1 = 75 μsec
▯ N_0 = 560 cps, T_1 = 121 μsec
+ N_0 = 560 cps, T_1 = 170 μsec
Theoretical curve (Eqs. 3, 12, 14)
Observed Counting Rate, N (cps)
2,000
1,000
0
0 500 1,000 1,500 2,000 2,500 3,000
Resolution Time, T_2 (μsec)

FIG. 8. Resolution loss when T_2 is comparable with T_1

arrival of photoelectrons produced at the cathode (*16*); Fig. 6 shows typical experimental results. Recently, spurious pulses have been observed from scintillation counters (*17–19*).

Random. The output of a windowless proportional counter was amplified and allowed to deflect a cathode-ray-oscilloscope spot. The time base was provided by a Dumont type 314-A oscillograph-record camera. Film speed was 10 in./sec, resolving pulses 500 μsec apart.

The oscillograph record was analyzed by dividing the face of a microfilm reader into equal intervals representing equal times and counting the number of intervals containing k events for each value of k. This is then compared with the value computed from Eq. 1. Each pair of experimental (f) and computed (ϵ) values then provides a point for Fig. 5 that represents a composite of all photographs. Some 10,000 counts, from C^{14}, S^{35}, and Pb^{210} particle-emitting sources were analyzed by this method, and Eq. 1 was confirmed.

Resolution-loss experiments. Using the experimental arrangement of Fig. 4, with a commercial end-window Geiger detector, output of the deadtime univibrator could be determined and Eq. 2 verified. Univibrator resolution times, T_2, were large compared with Geiger-counter deadtime, T_1.

If N_0 is calculated from one point or from the average of several points by using Eq. 2, the theoretical curve then passes through all other experimental points, as can be seen from Fig. 7. This is true, within the experimental error ($<1\%$ for N, $<3\%$ for T_2) for losses up to 99%. This upholds Collinge's assertion (*4*) that the error for large counting losses in his experiment was probably caused by the Class A characteristics of his quench multivibrator at high counting rates. Care was taken in the present case to operate the deadtime univibrator Class B at all counting rates.

Resolution losses were also measured as a function of T_2 when T_2 assumed values comparable to T_1; the data are plotted in Fig. 8. When T_2 was less than T_1 the combined resolution loss was constant, as predicted. For $T_2 > T_1$ the losses are less than predicted by Eq. 4; in fact σ does not differ appreciably from T_2. This result was unexpected, but is in the right direction considering the behavior of Geiger tubes is Type I+II-Class A rather than Type II-Class B as assumed in our theory.

It has been clearly demonstrated by Baldinger and Huber (*6*) that when a second pulse occurs before the counter has recovered completely from a previous event, the deadtime of the second event will be shorter than average. Thus if the latter event results in an extension, $f(T_1)$ will be less than predicted by assuming idealized resolution characteristics for the Geiger counter. It should also be pointed out that the probability of spurious events is greatest where $f(T_1)$ is largest, and that spurious events reduce the net counting loss.

Various investigators (*4, 20–23*) have used quenching circuits to improve the characteristics of Geiger counters by suppressing spurious events and reducing deadtime. We have shown that accurate estimation of counting losses can be obtained when the deadtime of the quench circuit is not only known but is the determining resolution time.

* * *

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Electron Linear Accelerators for Radiation Processing

Electron beams from most high-output accelerators lack penetration for many products. The traveling-wave linear accelerator overcomes this limitation with adequate external beam power for process use

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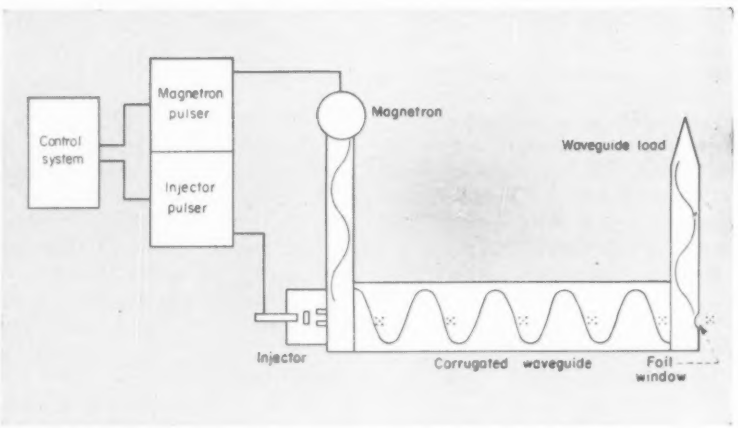
THE MOST SERIOUS inherent limitation of "direct" linear electron accelerators —the Van de Graaff, resonance transformer, capacitron and cascade units— is their electron beams' relatively short penetration even at the highest usual operating energies, commonly $1–3 \times 10^6$ volts.

While there are many promising process applications for 1–3-Mev electrons, canned goods and many meat products require considerably greater penetration. Some foods and pharmaceuticals that can be irradiated with direct accelerators could be treated more conveniently after packaging— when the over-all dimensions are considerably greater. Many products need electron beams above 5 Mev, frequently up to 10–15 Mev, with cross-firing techniques.

The electron-beam energy limitations of direct accelerators are of practical rather than fundamental nature. Because the electrons must acquire their energy by acceleration from a high-potential region to ground, the beam energy (in ev) can be no higher than the highest above-ground voltage that can be insulated practically.



BLOCK DIAGRAM of essential components of a traveling-wave electron accelerator. Electron injection is synchronized with the r-f power pulses

Direct-accelerator operating voltages higher than 3–4 Mev cause insulation requirements to increase the unit's over-all size so that it becomes unwieldy or uneconomic for many uses.

Several types of indirect accelerators have been developed for operation at very much higher energies—even up to several hundred Mev—without the dimensional requirements imposed by the direct method. These include the orbital accelerators, such as the betatron and electron synchrotron, and the r-f linear accelerators.

Orbital accelerators achieve high energy by subjecting electrons to repeated short-duration acceleration fields as the electrons travel around a relatively small diameter orbital path. But the electron-beam power output that can be withdrawn for external use is too small for practical processing.

The r-f linear accelerator imparts energy to electrons by setting up highly localized alternating or traveling fields along an evacuated straight-line accelerating path and subjecting suitably timed bunches of electrons to the accelerating action of these fields. The accelerating fields used are those associated with powerful short-duration pulses of radio-frequency waves.

With modern radar power tubes, the electron linear accelerator can achieve high beam energy over a relatively short total path length, of the order of

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one-fourth the length that would have to be insulated for direct acceleration in, for example, the 3–10-Mev range. Furthermore, recent developments have made possible total electron-beam power outputs sufficiently high for practical processing.

Design Requirements

In design of electron linear accelerators for processing use, general requirements are imposed by the geometry, processing rate, and radiation-dose needs of the material or product. Other requirements are economic. These are generally based on radiation costs as related to the value added by radiation, as well as possible competitive methods for adding equal value.

Energy range. The lower end of the electron energy range will be determined by the competitive economics of radiation from direct accelerators, and thus will be around 3–4 Mev. The upper energy limitations will be imposed by the probability of induced radioactivities in some products. Fortunately, the probabilities of such reactions yielding radioactivities of appreciable half-life and intensity are very low in the commercially interesting penetration ranges—up to 10–15 Mev. While existing information on nuclear side effects is encouraging, further studies will be needed before upper electron energy limitations can be established soundly for particular products.

Within this rather wide 3–10-Mev range, the energy selected will be determined by penetration requirements, taking into account the choices available in irradiation technique, such as cross-firing. Requirements for energy stability and homogeneity are not too demanding, and ±5–10% probably will be adequate.

Power output. The average electron beam power output—the product (kw) of the energy (Mev) and average beam current (milliamperes)—is still lower than many process needs and lower than power outputs achieved by direct machines. Restrictions stem from limitations in available r-f power sources and economic considerations. Presently, power outputs of a few kilowatts are considered practical, and substantially higher-powered apparatus are feasible.

Within limits, the power output is purely a function of the r-f power available and is reasonably independent of electron energy. The conversion efficiency from input line power to r-f power might be 20–30%; efficiencies of 40% have been achieved in converting r-f to electron beam power, and suitable design can increase this to 60–70%. Thus over-all efficiency might be 10–15%.

For efficient utilization of the electron-beam power, linear accelerators can draw on techniques worked out on direct accelerators (*1*, *2*), including beam scanning and cross-firing with or without filtration. The optimum technique is determined by the geometry of the product to be treated.

Reliability. Industrial accelerators must be highly reliable. This means predictability sufficient that preventive maintenance can minimize down-time. Accelerators must be designed so that maintenance personnel can service them straightforwardly, with minimum special skill and apparatus. Operation should approach the simplicity of an "on-off" switch, and long periods of unattended operation are desirable.

Economics. With respect to economic requirements, it is obvious that the cost per kilowatt of radiation absorbed in the process should be as low as possible. This means not only that development work should be directed to reduction of initial cost, but also strongly toward simplicity and dependability of operation, and to achievement of high radiation utilization efficiencies through uniform product dose.

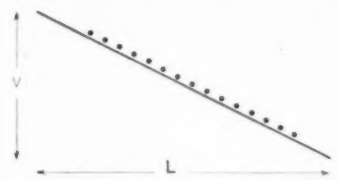
For the immediate future, capital costs of 5–15-Mev linear accelerators might be somewhat higher than those of 2–3-Mev direct accelerators of comparable power. Amortization of capital cost will be the most important economic factor in radiation processing.

Of considerably less importance than amortization, but still of significance, are hourly costs to be allocated for periodic replacement of the r-f power tubes. These might cost $2,000–8,000. Their useful operating life in a high-powered processing accelerator is not known yet. Salvage or reworking cost also should be considered in selecting an r-f tube type.

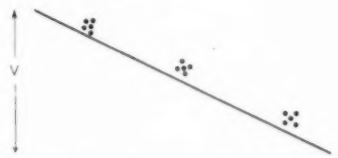
As with direct accelerators, hourly cost of input electric power is virtually negligible in comparison with amortization. Improved efficiency is of considerable importance in increasing unit power output, and thereby reducing capital cost. The importance of new high-frequency r-f sources to future development cannot be overestimated, whether they are developed especially or become available from other fields, such as radar and communications.

The electron linear accelerator is a promising and valuable addition to the list of radiation-processing tools. Its further development will parallel the continuing development of powerful direct accelerators. Together, these programs should assure a wide range of radiation sources for future exploitation of the many valuable and unique results now being realized on a research or pilot-plant scale.

How Electrons Can Be Accelerated



A DIRECT-TYPE accelerator uses a uniform field and uniform distribution to accelerate electrons along a tube.



INSTEAD OF uniform distribution of electrons along the tube, they could be injected and accelerated in bunches, but the intervening field serves no purpose.

SMALL LOCALIZED traveling fields of the same slope V/L could replace the steady field to produce the same accelerating effect.

HIGHER FIELD strengths become practical because there are no very high total voltages to insulate.

A SINUSOIDAL traveling-wave accelerates bunched electrons along a waveguide

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Progress in Radiobiology

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FOCAL POINTS OF RESEARCH in radiobiology remain essentially unchanged; considerable interest continues to be placed on mechanisms of energy transfer, the nature of early biochemical effects, and modes of chemical and biological protection. This was indicated at the Liège Conference (August 30–September 1, 1954), the second in a series of annual meetings devoted to radiobiology (1953 meeting, NU, Dec. '53, p. 18).

Although emphasis will be placed in this report on new data and interpretations, it is not always easy to disentangle the old from the new in evaluating advances in an active field. Complete coverage of the more than 50 papers presented is not intended.

Physico-Chemical Interactions

Indirect evidence for intra and intermolecular transfer of energy under conditions of "direct action" was presented by **P. Alexander** (Imperial College of Science and Technology, London), who observed that the degradation of solid polymethylmethacrylate (Perspex) by γ-irradiation could be decreased by adding small quantities of various substances to the polymer; Benzene-ring substances were particularly effective. Protection under these conditions is a result apparently of a polymer-to-additive energy transfer.

While this may be a special case, one may infer from it that chemical protectability is not necessarily a consequence of indirect action through the aqueous medium.

Application of the spatial relationships of radiation events to study of biological structure was discussed by **E. Pollard** (Yale University, New Haven, Conn). Ejection of an electron during the ionization process is believed to be followed by a rapid intramolecular transfer of the residual "positive character" with its eventual dissipation at sites vulnerable to breakage. The various functions of enzymes and viruses differ in their radiosensitivity, e.g., the cross section for inactivation of dry invertase was greater for enzymatic than for serological effects. With viruses, infectivity showed the greatest sensitivity, whereas serological and attachment functions seemed most resistant.

Effects in aqueous systems are complicated by additional pathways for energy transfer. Molecular and radical reactions in water under varying conditions of radiation dosage, oxygen tension and *p*H were reviewed by **M. Ebert** (Hammersmith Hospital, London). With high doses, the yield of hydrogen peroxide is directly proportional to oxygen tension; with comparatively lower doses (about 3×10^4 rad), a small change in oxygen tension leads to a large change in yield if the oxygen tension is low. This effect is greater at acid *p*H. The oxygen tension necessary to influence hydrogen peroxide formation was calculated for model systems; however, in view of the uncertainty concerning cellular oxygen tension, these calculations are not directly applicable to tissue. **J. St. L. Philpot** (Atomic Energy Research Establishment, Harwell, England) reported that several types of peroxides may be present in the mouse 15 min after irradiation.

Further evidence for the radiation inactivation of bacteriophage (S13) by reducing radicals was presented by **T. Alper** (Hammersmith Hospital, London). It is believed that phage is inactivated by H radicals in deoxygenated suspensions and by O_2^- radical ions in an oxygenated medium. It may be recalled that most, but not all, radiation reactions are believed to be oxidative in nature. When the exposure time was brief and sampling occurred immediately after irradiation, the inactivation dose in phage suspensions equilibrated with various gases increased from hydrogen to nitrogen to oxygen and was greatest in oxygen-hydrogen mixtures. It is interesting that the inactivation efficiency with high-dose-rate irradiation and immediate sampling was least when the yield of hydrogen peroxide was greatest. However, when the irradiation period or the time of sampling was prolonged, hydrogen peroxide served as an inactivating agent. Under these conditions, augmentation of radiation effects by oxygen may be due to the intermediary of hydrogen peroxide, which functions as a temporary reservoir of free radicals.

According to **R. Latarjet** (Institut du Radium, Paris), the transforming principle (TP), which confers resistance to pneumococci against streptomycin, is more sensitive to indirect effects of X-rays than is bacteriophage. It was suggested that the absence of a protein membrane and molecule dissymmetry increased the surface for free-radical reactions. Unlike nucleic acids and bacteriophage, TP inactivation was not affected by oxygen, and there was no aftereffect. The inactivation was considered to be not unlike that involved in producing gene mutations.

Biochemical Effects

How ionizing radiations affect cell constituents was reviewed by **M. Errera** (U. libre de Bruxelles, Brussels), who noted that the only obvious immediate effect appeared to be on DNA metabolism, perhaps as a reflection of the intimate relationship between DNA constituents and cell processes. It was suggested that establishing limiting conditions for cell components might help unravel radiation-induced changes, e.g., on protein synthesis and respiration.

Autoradiographic studies by **L. G. Lajtha** (U. of Oxford, England) of DNA synthesis in human-marrow cultures (uptake of P^{32}-labeled orthophosphate and of C^{14}-labeled adenine) revealed that synthesis occurred only for a limited time (12–15 hr), during the second half of the intermitotic period, and was completed several hours be-

fore metaphase. A 5,000-r dose completely inhibited DNA synthesis of cells in the synthetic period during irradiation. Cells in the first part of the intermitotic cycle could enter the synthetic stage but died after an abortive attempt at synthesis. Assembly of DNA from base, sugar and phosphate was sensitive to ionizing radiation but not to aminopterin. However, incorporation of formate into DNA was inhibited markedly by the folic acid antagonist and by X-rays as well.

According to **A. Nizet** (U. de Liège), a factor in irradiated plasma accelerates synthesis of hemoglobin by dog reticulocytes, whether plasma is irradiated *in vitro* or *in vivo*. The incorporation of C^{14} into liver glycogen in X-irradiated animals was studied by **M. Lourau-Pitres** (Institut de Biologie Physico-Chimique and Institut du Radium, Paris) with the conclusion that the synthesis of new glycogen, but not its turnover, was affected by irradiation. Exhalation of $C^{14}O_2$ after injection of labeled bicarbonate into total-body-irradiated mice was described by **A. Forrsberg** (Institute of Radiophysics, Stockholm). Irradiated mice exhaled $C^{14}O_2$ at a greatly decreased rate for a few minutes after intraperitoneal injection of bicarbonate. It was suggested that this might be due to a decrease in absorption rate since it was not observed after intravenous administration.

D. W. Van Bekkum (National Defense Research Council, Rijswijk, The Netherlands) suggested that decreased phosphorylation of spleen mitochondria, after total-body irradiation as low as 50–100 r, probably resulted from an indeterminate block in oxidation-coupled phosphorylating reactions. The disturbance was not related to the increase in ATP-ase activity or to other cytoplasmic factors. Oxidative phosphorylation decreased as early as 4 hr after irradiation. The significance of this change is not obvious; Mole noted that morphological damage is already apparent at this time. Effects of X-rays on acid-soluble phosphates and on respiration of the skin of rats were discussed by **P. Mandel** (Faculté de Médicine, Strasbourg, France), who indicated that energy-rich phosphates were decreased during the first days after irradiation.

In reviewing the action of ionizing radiations on lipids and lipid metabolism, **A. Chevallier** (Faculté de Médicine, Strasbourg) concluded that it was difficult at present to determine whether changes, when observed, resulted from a primary irradiation effect, for example by action of oxidizing radicals, or from some more physiological alteration.

Sensitivity, Effectiveness

Differentiation between radiosensitivity and biological effectiveness is of considerable theoretical importance and reflects a point of emphasis, namely between the biological system and the radiation, respectively. There is, needless to say, a large indeterminate area between the two.

J. S. Kirby-Smith (Biology Div., Oak Ridge National Laboratory) reported that 60–80-kv X-rays were about 1.5 times as effective as 200-kv X-rays and twice as effective as Co^{60} γ-rays (1.2 Mev) for producing chromosome breaks in dry Tradescantia pollen. The relative biological effectiveness (RBE) was about 10 for cyclotron fast neutrons compared to high-energy γ-rays. The magnitude of the differences generally conforms to the pattern previously reported by **L. H. Gray** (Mount Vernon Hospital, London), who noted that the variation of efficiency with ion density was large between 200-kv X-rays and 2-Mev neutrons and comparatively small between 200-kv X-rays and harder radiations.

R. H. Mole (AERE) employed sterilization and reduction in testes weight as damage indicators after varying patterns of chronic fast-neutron (graphite reactor) and γ-ray (Co^{60}) irradiation. Dose-response curves for weekly irradiation were qualitatively similar. The RBE was 3.5 for sterility in female CBA mice and about 6 for males. The RBE for this effect did not appear to increase greatly with increased exposure time; it may be recalled that protraction is believed to increase the RBE for several biological effects, presumably because of differences in recovery rates with the various radiations. The RBE for testicular atrophy in CBA mice was 3 to 4. Significant differences in RBE among strains of mice could be attributed to differences in the response to (presumably recovery from) γ-irradiation, the effectiveness of fast neutrons being the same in each instance.

L. Ehrenberg (U. of Stockholm, Stockholm), reported a qualitative difference between X-rays and fast neutrons regarding the influence of various post-irradiation factors on barley growth inhibition. X-irradiated moist, but not dry, seeds showed more damage when they were sown at 12° C than at 25° C. This effect was reversed when the moist seeds were stored at the low and high temperatures for a week or two before sowing. Germination and storage temperatures did not modify fast-neutron damage.

I. Lasnitzki (Strangeways Research Laboratory, Cambridge, England) observed that Ehrlich ascites tumor cells kept at −79° C for one week were more sensitive to γ- or X-ray effects than fresh cells—whether the frozen cells were given a 20-min exposure to 1,500 r at −79° C or at room temperature when they were presumably thawing. Cell viability remained unimpaired by freezing alone. The reason for this effect is not obvious; a converse situation might have been anticipated.

C. P. Swanson (Johns Hopkins U., Baltimore) interpreted the oxygen effect on chromosome breakage, based mainly on experiences with Tradescantia, in an attempt to rationalize the inadequacies of the breakage and restitution hypotheses. In this scheme oxygen was considered to increase chromosomal damage through indirect energy transfer and also by favoring conversion of potential to primary breaks. Since densely ionizing radiations lead mainly to primary breaks, the oxygen effect is small. The ratios of potential to primary breaks and of single- to double-strand chromosome lesions contribute to the different air-nitrogen sensitivities for the various chromatid aberrations. The fate of actual breaks in Tradescantia is apparently not influenced by oxygen, but this possibility may be important in other situations.

Studies of the X-ray sensitivity of bacteria as reflected by changes in oxygen consumption or anaerobic fermentation were reported by **H. Laser** (U. of Cambridge, England). Carbon monoxide, potassium cyanide, hydroxylamine or azide suppressed the oxygen effect in Sarcina lutea; it was suggested that the influence of oxygen was through reducing rather than oxidizing reactions. These results, however, do not necessarily deny an oxygen effect on oxidizing-radical yield. Stabilizing

a cell in a reduced state, e.g., by KCN, might, under some conditions, serve to buffer additional oxidants formed through the intermediary of oxygen; hence the effect might actually resemble one in the absence of oxygen.

Physico-chemical methods of protecting synthetic macromolecules against ionizing radiations were considered by **Alexander.** Protection was shown to occur by competition for free radicals, intramolecular modification of energy transfer as described earlier, and the repair or stabilization of an activated macromolecule. An example of the latter was provided when aqueous solutions of polyvinyl alcohol were irradiated. Irradiation was conceived to result in loss of hydrogen with polymer-radical formation. Polymer-radical degradation through peroxy-radical intermediaries can be prevented by adding suitable hydrogen donors. In the absence of oxygen, the polymer radical does not degrade but crosslinks to form a gel. Hydrogen donors can reconstitute the polymer and prevent crosslinking.

A skin test utilizing the "reciprocal vicinity effect" of irradiated areas was introduced by **B. Jolles** (General Hospital, Northampton, England). An application to the screening of protective substances was suggested, but this appears to be limited.

Requirements for cysteamine (beta-mercaptoethylamine) protection of *E. coli* against the lethal effects of X-rays were discussed by **A. Hollaender** (Biology Div., ORNL). A high level of protection occurred only when the bacteria were grown on certain media after irradiation, e.g., one containing glutamate, uracil and guanine. Protection was markedly reduced by phosphates present during irradiation. This was not the case with mercaptoethanol. The complexity of the cysteamine effect in this particular system was indicated also by its protective additivity with other agents. It is of interest that the lethal effect of an organic peroxide on bacteria was enhanced when cysteamine was added after the toxic agent, whereas the reverse situation was protective (**Laterjet**).

Possible mechanisms in the protection of animals by sulfhydryl substances, e.g., cysteine and cysteamine, were reviewed by **H. M. Patt** (Argonne National Laboratory, Lemont, Ill.) with the conclusion that most of these effects can, at present, be interpreted best in terms of reactive intermediates formed in irradiated water. Protection by SH substances is probably related to their serving as hydrogen donors; both destructive and regenerative processes can be modified by these agents. The importance of evaluating protective effects in terms of dose-response relationships and other physiological variables was emphasized. Regarding the latter, **L. Eldjarn** (Norwegian Radium Hospital, Oslo) found a selective distribution of cysteamine and cystamine in various rat tissues after subcutaneous injection of S^{35}-labeled compounds. *In vitro* and *in vivo* biochemical studies indicate that the protective effect of cysteamine might be explained by radical capture and that certain contradictory evidence might be accounted for by differences in its concentration in various tissues. The observation by **S. Neukomm** (U. de Liège, Lausanne) that cysteamine did not modify the growth inhibition of a rat mammary tumor resulting from local X-irradiation *in vivo* could be interpreted in this way. Along these lines, **M. A. Gerebtzoff** (U. de Liège, Liège) reported that injection of cysteamine in mice before 700-r X-irradiation decreased the early (6-hr) degeneration in spleen and liver but not in thymus and intestine. Regeneration of spleen and intestine appeared to be more rapid in the treated animals. The suggestion was made that cysteamine protection was manifest in some indeterminate manner at the level of factors concerned with glycogen metabolism; however, the supporting data are incomplete and subject to other interpretations.

Laboratory and clinical trials with chemicals that may act as radiosensitizers were reported by **J. S. Mitchell** (U. of Cambridge). Much of the work was concerned with Synkavit (tetrasodium 2-methyl-1:4-naphthohydroquinon diphosphate), which enhances radiation effects on chick fibroblasts and the Walker rat carcinoma. Radiosensitivity resulting from initial treatment of the fibroblast cultures persisted in the subcultures even after 16 passages. Post-irradiation Synkavit exerted a minimal effect on tumor regression in rats in contrast to its efficacy when given before the exposure. Distribution studies indicate that Synkavit is concentrated selectively by tumor cells when given intravenously in low doses. Synkavit treatment combined with total-body X-irradiation may enhance somewhat the acute lethality in rats but not in rabbits, according to **J. O. Laws** (Dept. of Experimental Pathology and Cancer Research, Leeds U., England); over-all effects of this substance in irradiated animals appeared to be minimal. **Gray** emphasized the necessity for defining a radiosensitizer; from the point of view of mechanism, it is important to know whether one is dealing with the potentiation of an effect of one agent by another or with the summation of effects resulting from the two different agents.

Cellular Effects

The physiological control of mutation production in streptomyces by ultraviolet and X-irradiation was considered by **H. B. Newcombe** (Atomic Energy of Canada Ltd., Ontario). Essentially similar nonlinear dose-mutation curves were obtained with the two qualities of radiation, which were only partially additive in their effect. Changes in mutability in each instance appeared to be associated with various nuclear states. The proportion of induced mutants was more than doubled with binucleate spores and then declined with further increase in the number of nuclei.

J. G. Carlson (U. of Tennessee, Oak Ridge) reported that X-ray induced stickiness of the chromosomes of grasshopper neuroblasts required a lower dose the earlier the cell stage. This may reflect the differential sensitivity of chromosomes at different stages of mitosis or may be merely a manifestation of the time available for stickiness to develop.

S. H. Revell (Royal Cancer Hospital, London) suggested that chromatid changes induced by diepoxide and by ionizing radiation were essentially similar and occurred only at points where chromosomes were in contact. According to this view, chromatid exchanges would involve only heterologous points in contact on the same chromosome or associated parts of different chromosomes. **Gray** pointed out that the mechanisms of chromosome breakage and exchange by chemicals and by ionizing radiations need not be identical nor involve exact points of contact. He noted that interchanges were linear with the dose of diepoxide and increased as the

square of the X-ray dose. Differences in the types of reunion in Tradescantia chromosomes after treatment with X-rays and diepoxide were reported by **G. Roy-Lane** (Southampton, England). With diepoxide, reunion was entirely between chromatids whereas with X-rays chromosome reunion was also apparent. **E. E. Deschner** (Brookhaven National Laboratory, Upton, N. Y.) reported that changes in the radiosensitivity of Trillium chromosomes to breakage during various stages of microsporogenesis were not related necessarily to effects on rejoining.

Pathological Physiology

B. Rajewski (U. of Frankfurt, Germany) reported that acute (3–5 day) lethality of mice resulting from large doses of whole-body X-irradiation was independent of exposure times of 2.5 sec to 12 hr. Fractionation of the total dose did not modify the effect unless successive fractions were separated by 24 hr or longer. It was suggested that the 3–5 day killing of mice might be related to a pituitary-adrenal effect.

The thesis that hypercorticism may be a contributing factor in inhibiting blood formation after whole-body irradiation was investigated by **H. Betz** (U. de Liège). Although a large dose of cortisone could inhibit hematopoietic regeneration in irradiated rats, the results of the more critical experiments were inconclusive. However, somatotrophic hormone, testosterone, and vitamin B12 enhanced somewhat the regeneration of blood-forming tissues, but only in adrenalectomized animals. Thus, these substances and the adrenal hormones were antagonistic in their action; this might be related to their differential effect on protein metabolism, which in turn was related to hematopoietic regeneration.

L. A. Elson (Royal Cancer Hospital, London) reported that "Myleran," 1:4 dimethanesulfonyloxybutane, reproduced mainly the myeloid effects of X-radiation in rats while nitrogen mustards led, for the most part, to lymphoid effects. Administration of both agents resulted in blood and body-weight changes comparable to those of whole-body X-irradiation.

Observations made on humans after single local or whole-body doses of X-rays were described by **W. Court-Brown** (London). The latent period between irradiation and the onset of symptoms depended on the dose, body size, and the sensitivity of the irradiated site; it was linearly related to the log dose per unit of body size for any given irradiation site. It was suggested that the time of onset and severity of the initial illness were a manifestation of the release of diffusible substances from the irradiated volume and the extent of their dilution in the remainder of the body. Changes in the leucocyte count during this period were not characteristic of those induced by ACTH, epinephrine or histamine; adrenal function was apparently not disturbed before or during the onset of clinical radiation sickness.

Biological Protection

In contrast to many chemical protective effects, which are believed to be related somehow to energy-transfer mechanisms, other procedures are apparently more selective and concerned with the events responsible for injury to, or recovery of, specific physiological systems. Effects of tissue shielding and transplants fall into the latter category and may be thought of as examples of biological protection.

Modification of radiation responses by shielding procedures was considered by **L. F. Lamerton** (Royal Cancer Hospital, London), who used sublethal exposures to facilitate study of the recovery phase. Shielding small volumes of active marrow minimized thrombocytopenia because of megakaryocyte activity in the shielded part. Bleeding and anemia were also diminished. Radioiron uptake showed that the spleen recovered erythropoietic function earlier than bone marrow after whole-body X-irradiation with 450 r. When a limb was shielded, an initially high iron uptake was seen in the shielded part, and splenic erythropoiesis developed at an earlier stage than in the case of unshielded animals. Absence of the spleen did not appear to modify the over-all effect of limb shielding on erythropoietic recovery.

J. Maison (Institut de Cancer, Louvain, Switzerland) reported that shielding intestinal loops and bone marrow in X-irradiated rats was more effective in promoting survival than shielding either alone. Intestinal shielding alone decreased somewhat the early body weight loss; this was not seen with bone marrow shielding, which, however, minimized subsequent weight changes, presumably because of the increased well-being associated with earlier hematopoietic recovery. Injection of cysteamine enhanced the protective effect of bone-marrow shielding or marrow injection in X-irradiated rats.

Effects of spleen shielding and injection of cell suspensions on survival of X-irradiated mice were reviewed by **L. O. Jacobson** (U. of Chicago). A relatively small total number of cells, about 1×10^5 marrow cells, was sufficient to increase survival when injected soon after X-irradiation. It was argued that morphologically intact cells may be necessary for radiation protective effects of this sort in contrast to the interpretation of **Cole** of a subcellular recovery factor resembling a DNA protein. It was noted that a homogenization-fractionation technique similar to that employed by Cole did not affect the leukemia-inducing capacity of suspensions of leukemic cells.

J. Loutit (AERE, Harwell) reported a mouse-strain specificity in the action of spleen homogenates that was manifest when survival was followed on a long-term basis, i.e., beyond the usual 30-day period. The active agent in spleen homogenates was quite labile; it could be stabilized somewhat by procedures that are believed to preserve cells. Immunizing mice with spleens from another strain decreased protective activity when similar spleen preparations were given sometime later. This, however, does not prove that intact cells were required for the protective effect.

According to **L. J. Cole** (U. S. Naval Radiological Defense Laboratory, San Francisco), the spleen recovery factor is insoluble and particulate, associated with the nuclear fraction, nondialyzable and thermally unstable, and inactivated by ultrasonic or X-radiation, lyophilization, and treatment with trypsin or desoxyribonuclease. It was shown that the DNA present in intact nonhomogenized spleen cells was not available as a substrate for added DNA-ase. This was interpreted as further support for the conclusion that the active agent in suitably prepared spleen homogenates is a DNA protein rather than an intact cell. It was generally agreed that further work is required to establish the precise nature of these protective effects. END

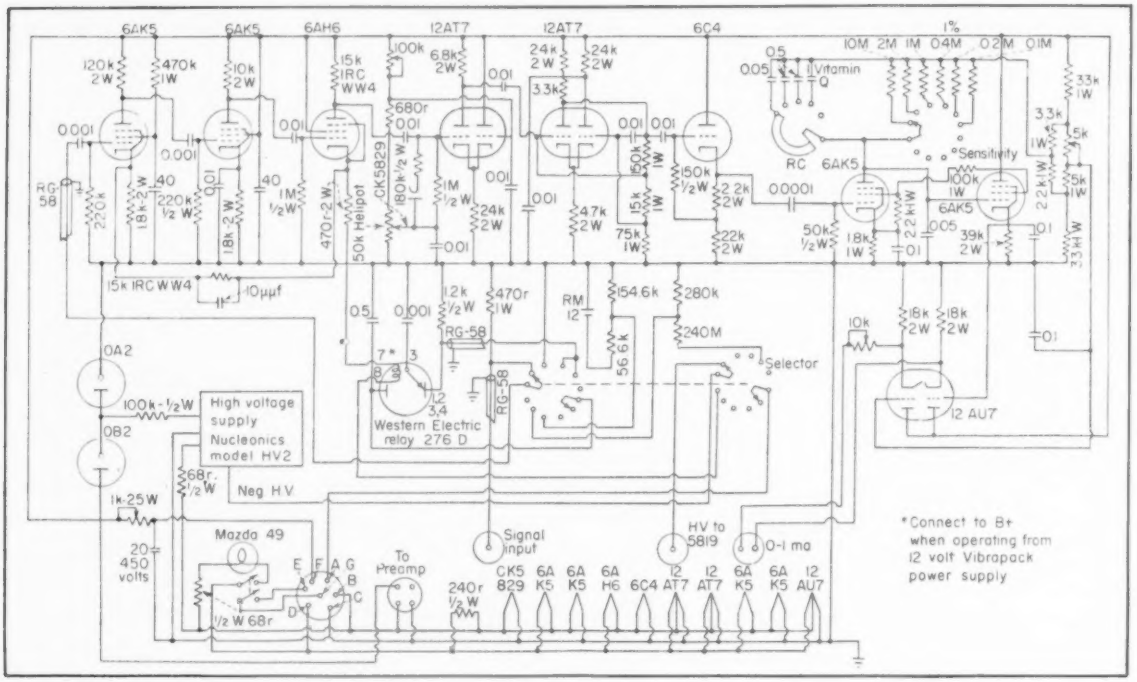

FIG. 1. Amplifier and counting-rate meter circuit

Scintillation Detector for Carborne and Airborne Use

By F. J. DAVIS, J. A. HARTER, P. W. REINHARDT, and C. F. HARRIS*
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A scintillation detector has been developed specifically for geologists and prospectors, taking into consideration the needs and operating conditions that one encounters while operating radiation detection equipment in the field.

The equipment weighs 31 lb, not including the recorder and scintillation head, and is operated from either the 6-volt or 12-volt storage battery of any car or light aircraft. Rapid calibration and standardization are possible at any time during field operations by such features as built-in standardization of amplifier gain and high voltage, and counting-rate meter calibration.

The amplifier-ratemeter circuit (Fig. 1) was designed for reliability and stability rather than for simplicity. The amplifier is essentially the same as the first three-tube feedback loop of the Bell and Jordan general-purpose linear amplifier.†

Miniature tubes have been used in the amplifier and discriminator circuit to conserve space and weight. Considerable stability to temperature changes was obtained by using a noninductive wire-wound resistor in the feedback loop. The ratemeter circuit has sensitivity ranges of 2, 10, 20, 50, 100 and 200 cps/division (100 divisions, full scale) with an output suitable for driving a 0–1 ma recorder. Various RC

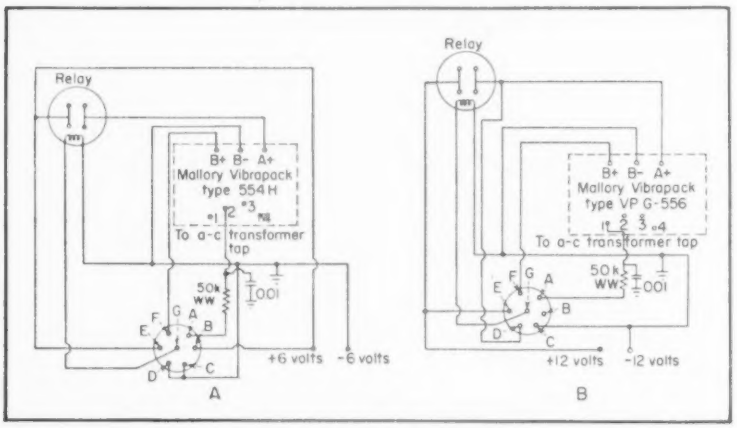

FIG. 2. Vibrapack power supply: (A) 6 volt and (B) 12 volt

* PRESENT ADDRESS: Oklahoma A and M, Stillwater, Oklahoma.

† W. H. Jordan, P. R. Bell, *Rev. Sci. Instr.* **18**, 703 (1947).

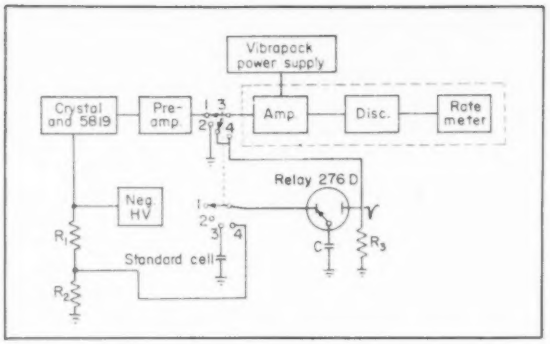

FIG. 3. Q pulser calibration system

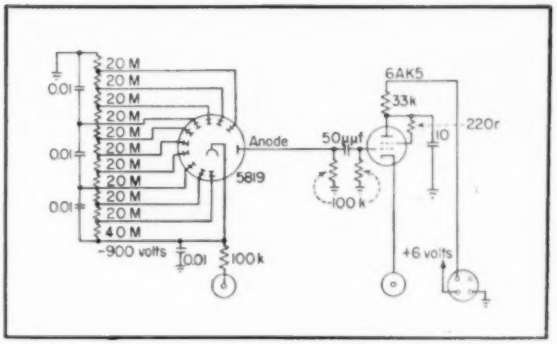

FIG. 4. Photomultiplier and preamplifier circuit

time constants can be chosen. The positions of the RC switch are designated as $1/S$, $10/S$, $20/S$ and $40/S$, where S is the sensitivity at which the ratemeter is operated. For example, at a sensitivity of 20 cps/division and a RC setting of $10/S$, the RC time constant would be $^{10}/_{20}$ or $^{1}/_{2}$ sec. The tube filaments are wired so that the same power cables can be used to convert the system directly to either a 6-volt or 12-volt Vibrapack power supply shown in Fig. 2A and 2B.

A built-in, simplified mercury Q pulser‡ is used to standardize the amplifier and ratemeter, and to monitor the high voltage supply (Fig. 3). By switching the selector switch to position 3, a d-c standard voltage is fed into the input of the mercury relay Q pulser from either a standard cell or a high-impedance voltage divider across a Mallory RM-12 mercury cell.§ The output pulse generated from this standard voltage is fed into the amplifier for calibration of the discriminator. By switching the selector switch to position 4, the input terminal of the Q pulser is then switched to a voltage divider consisting of R_1 and R_2 across the high voltage supply. By proper selection of R_1 and R_2, the voltage across R_2 can be made equal in amplitude to the reference voltage at the desired high voltage setting. Any change in the high voltage output can then be detected by a shift between this discriminator threshold setting and the standard pulse threshold setting.

The mercury relay is driven from the power transformer in the Vibrapack power supply; the vibrator has a resonant frequency of approximately 118 cps, making it possible to check the ratemeter calibration, as well as the amplifier gain and high voltage. The photomultiplier and preamplifier circuit is shown in Fig. 4. Any similar circuit can be used, provided the 5819 voltage divider drain is less than the 10 μa current limit of this high voltage supply.

A large NaI(Tl) crystal, such as the 4×2 in. crystals used in the equipment of the U. S. Geological Survey¶ for aerial prospecting, is recommended to minimize the statistical error.

‡ ORNL Circuit No. Q 1066.

§ J. M. Booe, *J. Electrochem. Soc.* **99**, 197 (1952).

¶ Report in preparation.

Gain Variation of Photomultiplier Tubes

By R. L. CALDWELL and S. E. TURNER
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It is generally thought that both RCA 5819 and Dumont 6292 photomultiplier tubes have excellent gain stability.* Recent experiments in these laboratories have revealed a dependence of gain upon source intensity and recent counting history.

In the course of γ-ray spectral analyses with a scintillation crystal spectrometer, repeated accurate calibrations with a weak Cs^{137} source showed a continual change in gain of the spectrometer. Monitoring of the high voltage power supply to the photomultiplier tube and calibration of the linear-amplifier gain showed that the photomultiplier gain increased during the counting interval. The gain increase was enhanced by short exposure to a high-intensity γ-ray source. After the removal of this source a continuous gain decrease was observed;

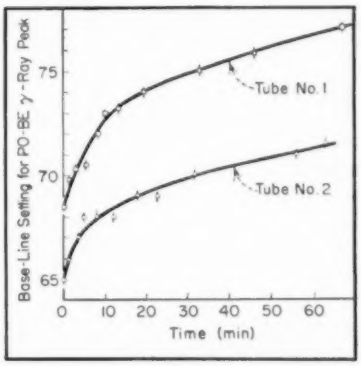


FIG. 1. Photomultiplier-gain increase due to continuous 0.8-mr/min Ra γ-irradiation

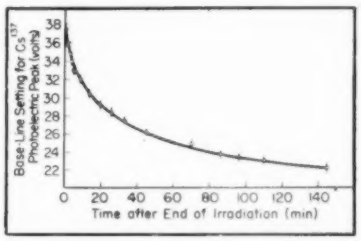


FIG. 2. Gain decrease of the tube after Cs γ-irradiation

* Scintillation Counting today, NUCLEONICS **12**, No. 3, 28 (1954).

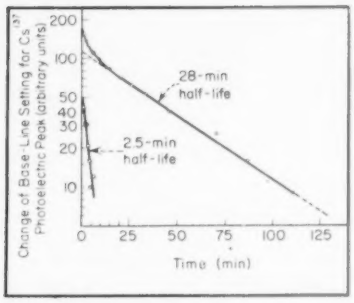


FIG. 3. Incremental tube-gain decrease after Cs γ-irradiation

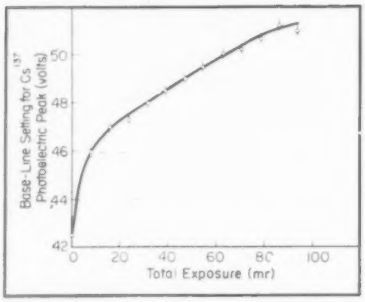


FIG. 4. Tube-gain increase due to intermittent Cs γ-irradiations

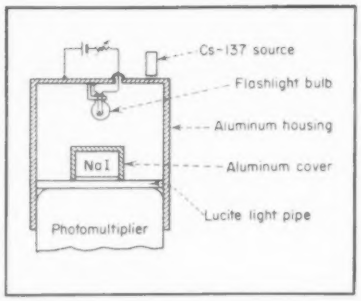


FIG. 5. Arrangement for incandescent-light exposures

whether this effect is due to "sensitization" of the photocathode or the dynode material has not been established. Measurements indicate that no large resolution losses result at the increased gains observed. The gain of five Dumont 6292 and two RCA 5819 tubes were checked at reasonably high counting rates. All of the 6292 tubes and none of the 5819 tubes showed the change-in-gain effects. The magnitude of the gain shifts observed are such as to introduce appreciable error in the measurement of high-energy peaks when relatively high intensities of low-energy radiation are present. It may be possible to minimize this effect by the optimum selection of bleeder resistor values.

Experiments

The scintillation crystal spectrometer consisted of a 1½-in. by 1½-in. sodium iodide crystal optically coupled to a photomultiplier tube, linear amplifier, single-channel pulse-height analyzer, and a scaler or counting-rate meter. The photomultiplier was operated at 86 volts on dynodes 3 through 10 and 340 and 170 volts on dynodes 1 and 2, respectively, with 510k bleeder resistors. The total photocathode voltage (−1,200 volts) was continuously monitored to ±0.2 volt. Gamma-ray intensities at the crystal from the various sources used were measured with two pocket ionization chambers.

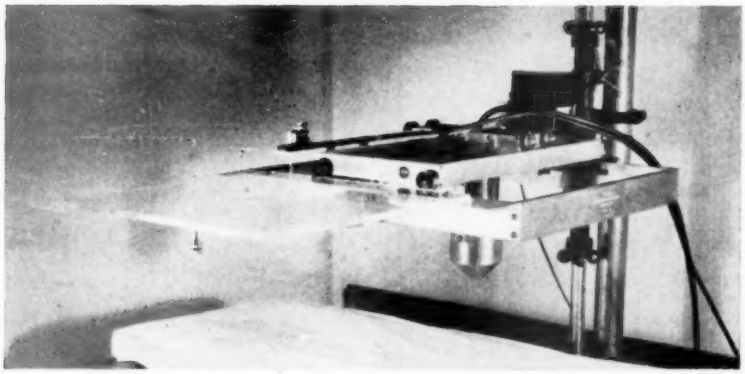
To observe the gain increase of a photomultiplier during irradiation, two γ-ray sources were used. A 4-curie Po-Be source, which emits 4.5-Mev γ-rays as well as neutrons, was placed 10 in. from the crystal to give 13 mr/hr. The principal pair-production peak due to the 4.5-Mev γ-rays was found with the single-channel pulse-height analyzer by reading the counting-rate meter. The base-line setting for this peak was checked more carefully by taking a series of readings with the scaler. At the end of 1 hr, the base-line setting was constant with time. Then a 10-mc radium source was placed 6 in. from the crystal to give an additional exposure of 45 mr/hr. Although the radium source has a maximum γ-ray energy of about 2.3 Mev, a large fraction of the γ-rays emitted have a much lower energy. The 4.5-Mev Po-Be γ-rays were easily resolved above the high intensity of lower-energy radium pulses. The base-line setting of the analyzer for the strongest peak due to the 4.5-Mev γ-rays was determined at regular intervals to give a growth curve of the photomultiplier gain. Figure 1 shows the curves for two Dumont 6292 tubes.

To observe the gain decrease of the photomultiplier after its use at a high counting rate, a 100-mc Cs^{137} source was placed near the crystal for 3 min to give a total irradiation of about 400 mr. At the end of irradiation, a 5-μc cesium source was placed on top of the crystal. The base-line setting of the analyzer for the 0.66-Mev photoelectric peak was determined at regular intervals. Figure 2 is a typical decay curve of the gain of a Dumont 6292. Figure 3 is a curve of the incremental change of gain obtained by subtracting the initial base line setting (before irradiation) from the Fig. 2 data. A short half-life decay followed by a much longer-lived decay are apparent—about 2.5 and 28 min, respectively. A second Dumont 6292 tube showed similar performance. Two RCA 5819's gave no gain increase for similar irradiations. With no high voltage on a 6292 tube, an overnight irradiation of 9 r was made. Upon application of the high voltage, the tube gain was unchanged from its value before exposure.

A second experiment on gain increase was performed using the 100-mc Cs^{137} source to give brief, intermittent exposures at repeated intervals. A thick lead shutter between the source and crystal was used to control the exposure. Ten-second exposures, each 7.8 mr, were made at 2-min intervals. The 5-μc Cs^{137} source on the crystal was used for calibrating the tube gain. The base-line setting of the pulse-height analyzer for the photoelectric peak was observed at 1 min after the end of each 10-sec exposure. Figure 4 shows the gain-vs-total exposure curve for a Dumont 6292. This growth curve shows two components of about the same half-lives as observed in the decay curve.

A third experiment consisted of exposing the photomultiplier to an incandescent bulb mounted in a light-tight enclosure with a 1-in. diameter by ½-in.-thick NaI crystal on the tube (Fig. 5). The light entered the photomultiplier through the walls of the light pipe. After a 1-min light exposure, the tube gain was followed using the weak cesium source rigidly fastened to the light-tight enclosure. The decay curve of tube gain showed the same components found with γ-ray irradiation, establishing the effect to be within the tube and not the crystal. Exposure to different light intensities, as monitored by tube current, showed that the increase in photomultiplier gain is dependent upon the amount of light irradiation.

In none of the experiments was any permanent gain change observed. After sufficient time for decay following either γ-ray or light exposure, the tube gain returned to its original value.



ASSEMBLY MOUNTING is birail X-ray tubestand, which fits X-ray table; height is adjustable. Lateral views of neck can be obtained by rotating scanner 45 deg, avoiding patient's shoulder. Bottom-frame support ($2\frac{1}{2} \times \frac{1}{2}$ in. Duraluminum) holds rack that advances upper carriages ($1\frac{1}{2} \times \frac{3}{8}$ in. Duraluminum). Inside frame dimensions are: bottom, $20\frac{7}{8} \times 23$ in.; middle, $19\frac{7}{8} \times 10$ in.; top, $9\frac{7}{16} \times 3\frac{5}{16}$ in. Maximum field size is $12\frac{1}{4} \times 12\frac{1}{4}$ in.

Economical Scintillation Scanner

By THEODORE E. SOPP, SAMUEL V. GEYER, and J. STAUFFER LEHMAN

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Although the advantages of mechanically scanning radioactive-material concentrations *in vivo* are well established (*1–4*), the initial high cost of a "scintiscanner" presents an economic problem to the average institution. A low-cost scintiscanner has been constructed and is described here.

The various factors arising in designing scanning devices are field size, scanning speed, transverse and longitudinal motion, recording, and mounting. The scanning motions are accomplished by two upper carriages. A rack, attached to a bottom frame, advances the upper carriages. On the middle carriage are mounted the motor, lead screws, and advancing mechanism. The top carriage holds the scintillation detector and recording pen; its removal is simplified by half-nuts.

The speed at which the detector moves across the field controls, in part, the number of counts recorded. With due consideration to tube sensitivity, shielding, and amount of radioactivity, we elected to employ a scanning speed of 10 in. in $\frac{1}{2}$ min. A lead screw of 11 threads per inch is commercially available, requiring a screw rotation of 220 rpm. The reversible motor used has a speed of 5,000 rpm; a worm and worm wheel connection provides a speed reduction of about 25:1 between the motor and lead screw. A variable speed motor incorporating a counting-rate controlling circuit might be desirable (*5*); however, good results have been obtained with the described apparatus.

The recording device, a relay to which is attached a pointed brass rod, is mounted on an arm attached to the top carriage. When pulses from the scaler activate the solenoid, the brass rod taps the Lucite "desk." Carbon paper is placed between two or three sheets of paper and a dot is made by the brass rod.

* * *

The authors express sincere thanks to Mr. Edward Flamm, chief machinist of Hahnemann Medical College and Hospital, for his helpful suggestions and actual production of the instrument described.

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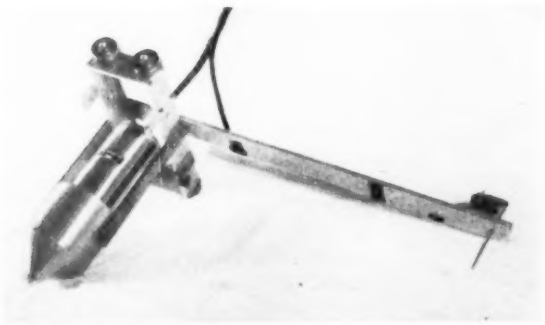
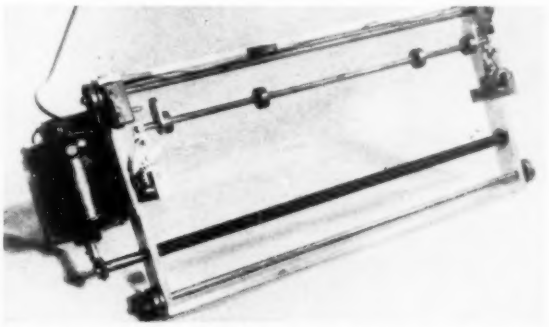


TOP CARRIAGE carries scintillation detector and recording pen in transverse motion. Two half-nuts, $2\frac{1}{2}$ in. from one end, engage lead screw of middle carriage; lugs $2\frac{1}{2}$ in. from other end activate reversing and advancement mechanism by impinging on inner collars on middle carriage; two microswitches and latching relay permit reversing. When upper-carriage lug pushes on inner collar, thrust-rod moves and outer collar pushes on switch; advancing mechanism operates at same time. Adjustable inner collar provide range of field sizes



MIDDLE CARRIAGE provides longitudinal motion, using same motor that drives lead screw, by means of rack-and-pinion drive; 12-in.-long rack is on bottom frame. To advance carriage $\frac{1}{16}$ in., ratchet and pawl device drives pinion. Thrust rod, moving under action of upper carriage, causes rack-and-pinion mechanism to rotate, thus advancing unit. After desired advance, microswitch is operated and motor reverses. During pinion rotation, pawl on opposite side is drawn back to be in position for next cycle

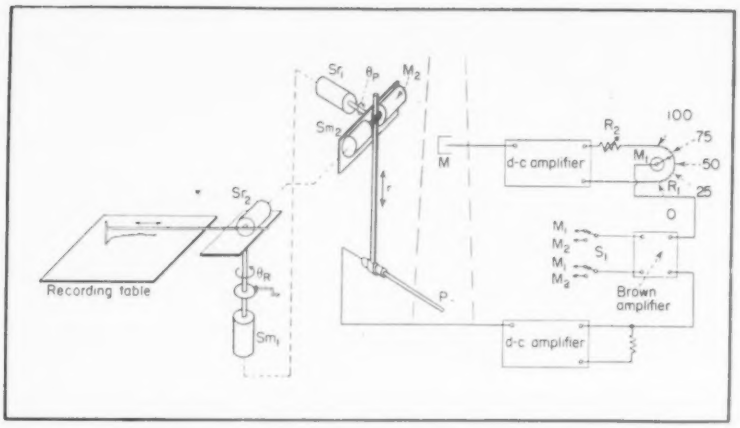


FIG. 1. Servo and selsyn system of ratio circuit and isodose recorder

Automatic Isodose Plotter

By G. A. MAUCHEL and H. E. JOHNS
Department of Physics, University of Saskatchewan and Cancer Clinic
Saskatoon, Saskatchewan, Canada

Without automatic devices, plotting isodose curves to indicate dosage distribution in a water phantom irradiated with X- or γ-rays is very laborious. A plotter that compares two integrated dosage rates was developed by Kemp several years ago (*1*). The plotter described here consists of two identical, simple d-c amplifiers and a commercially available servo system. With it, a set of ten isodose curves may be measured and plotted in about 10 min. They are independent of output fluctuations.

This system, consisting of a ratio circuit and an isodose plotter (Figs. 1–3), employs two independent ionization chambers: a monitor M and a probe P, which are placed in the same X-ray beam. The monitor is held in a fixed position whereas the probe can be moved to various positions in the water phantom. The monitor and probe ionization chambers are connected to two d-c amplifiers coupled so a variable fraction of the monitor output is balanced against the total output of the probe.

Used as Ratio Circuit

With the switch S_1 in the upper position (Fig. 1), the device is used as a ratio circuit (*2*). The balance is continually maintained by the servo motor M_1, which selects the proper fraction of monitor output to balance the probe output. The dial of R_1 indicates the ionization-current ratio at all times. With this arrangement, the ratio is independent of random fluctuations of output from the X-ray machine.

To measure percentage depth dose, the probe is first moved to the surface of the phantom and R_2 adjusted so that with the contact point of R_1 at the 100% end of R_1, balance is obtained. The dial of helipot R_1 reads 100 at this position. When the probe is moved to lower dosage rates, the servo motor M_1 automatically moves the contact along R_1 to maintain balance. The per cent depth dose is read directly off the dia- of helipot R_1.

The d-c amplifiers are identical; each consists of two battery-operated elecl trometer pentodes arranged with 100% negative feedback (Fig. 4). Details of the ratio circuit have been published elsewhere (*2*). When using the ratio circuit alone, a cartesian remote-control system for moving the probe through the water phantom is convenient (*3, 4*), but for isodose plotting, a polar system shown in Fig. 1 is more practical.

Used as Isodose Plotter

To use the device as an isodose plotter, switch S_1 (Fig. 1) is moved to the lower position. Any error signal from the ratio circuit activates motor M_2, moving the probe radially along a line through the origin of a set of plane polar coordinates, until the error signal is zero. In most cases, the isodose distribution is such that, as the probe moves further from the origin, the dosage rate decreases. Under these circumstances, when the probe signal is less than the selected fraction of the monitor signal, M_2 rotates in a clockwise direction moving the probe towards the origin. In the few cases where dose increases with depth, such as in the build-up region for high-energy radiation (*5*), a manually operated switch may be used to reverse the polarity of the error signal. The particular isodose curve followed by the probe depends on the setting of R_1. In most cases, one sets the probe at the position of maximum dosage in the water phantom and adjusts R_2 as previously described. The probe will now move to the depth corresponding to any percentage set on R_1.

FIG. 2. Probe-moving mechanism under 280-kv X-ray machine; monitor supported in corner of field and probe beneath surface of water phantom

FIG. 3. Recording system; from top to bottom: recording table, selsyn control panel, ratio circuit; top center is manually operated sweeping control

To follow an isodose curve, the radius vector r is rotated about the origin through some angle. This rotation is produced manually by rotating selsyn S_{m_1} in the control room (Fig. 1). In the control room, an identical system to the one carrying the probe is used, but a pen is mounted on the radius vector rather than a probe. The motion is confined to a horizontal rather than a vertical plane. Angular displacements θ_R of the pen arm are exactly reproduced by the angular displacement θ_P of the probe arm through the selsyn system $S_{m_1} - S_{r_1}$. Thus, the operator manually changes the position of the pen arm causing a similar change in the angular position of the probe arm. The servo motor M_2, as well as driving the probe to the proper depth, drives a selsyn generator S_{m_2}, which is coupled electrically to the selsyn motor S_{r_2} in the control room. The selsyn motor S_{r_2} moves the pen in exactly the same way as the probe is moved.

Manual control of the rate of angular displacement is convenient because it may be altered at will to suit the type of curve being followed. When the isodose curve approximates the arc of a circle of radius r, the angular sweep speed may be increased. Near the edges of the beam the sweep speed must be decreased to allow time for the servo system to move the probe to the balance point. Angular accuracy between θ_P and θ_R is achieved by gearing down the sweep selsyn 108:1.

The origin of the polar system is conveniently placed about 20 cm above the water surface. The operator need therefore turn the manually driven selsyn about ten turns to cover the field of radiation. This allows rapid angular sweeping and yet retains fine control where necessary. When the operator has completed one curve, he can lower the recorder table and set R_1 to the next desired value. When he sees that radial motion has ceased, he may raise the recorder table and draw the next curve.

Servo and Selsyn System

The servo system consists of a converter, Brown amplifier and two-phase motor. The probe-moving system is very slightly underdamped. This avoids errors during sweeping, which would arise, if critical damping were used, due to the servo system not being in a steady state. The slight oscillation due to underdamping is not at all bothersome and a smooth curve may be drawn through the pen trace with very little uncertainty.

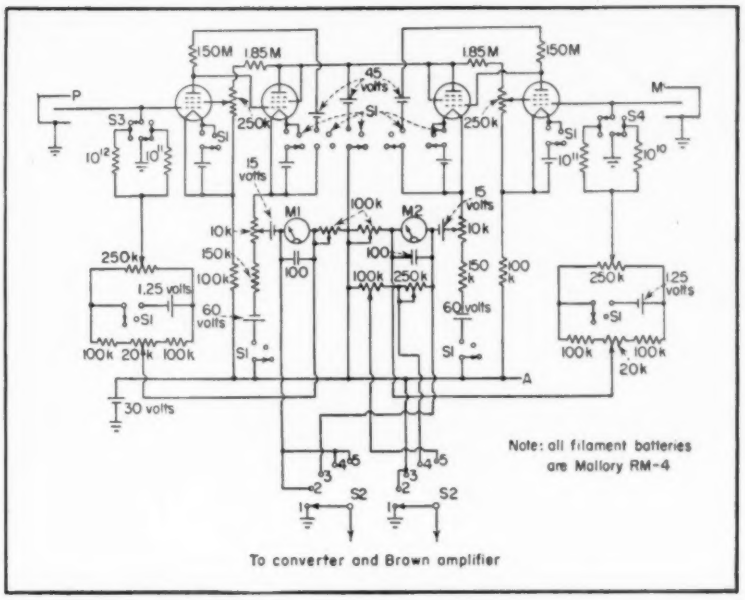


FIG. 4. Detailed ratio circuit

Error between the angular selsyns was kept to a negligible amount by gearing down the movements. For this selsyn arrangement

$$\theta_P - \theta_R = \frac{KT}{R^2}$$

over wide limits where K = constant depending on selsyns used, T = torque required to produce angular movement with no gearing down, and R = ratio by which selsyns are geared down. For the selsyns used, $K \cong 1$ deg error/oz-in.; T was about 150 oz-in. at the edge of the field with the probe attached. Therefore, assuming 100% efficiency in the gear trains

$$\theta_P - \theta_R \cong \frac{1 \times 150}{108 \times 108} \cong 0.013 \text{ deg}$$

In the radial movement, the selsyn motor is required only to move the pen arm in a horizontal plane by means of a rack-and-pinion system. The torque requirement is very small (< 5 oz-in.); with the rack and pinion used, a radial error of about 0.2 mm results, which is less than the width of the pen trace.

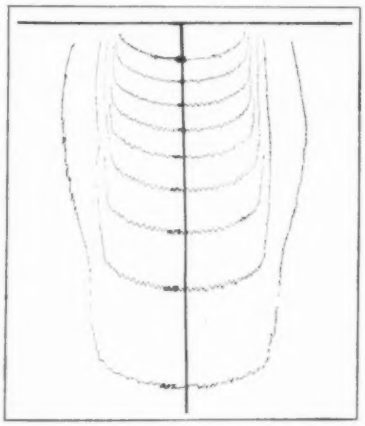


FIG. 5. Isodose curves obtained from 280-kv X-ray machine

Results

Figure 5 shows a typical set of curves taken from a 6 × 8 cm field of a 280-kv X-ray machine with half-value layer 2.5 mm of copper and source-to-skin distance 50 cm. The set shown was obtained in about 10 min. No effort was made to keep the output constant.

* * *

The authors wish to thank the National Cancer Institute for financial assistance in the development of this device.

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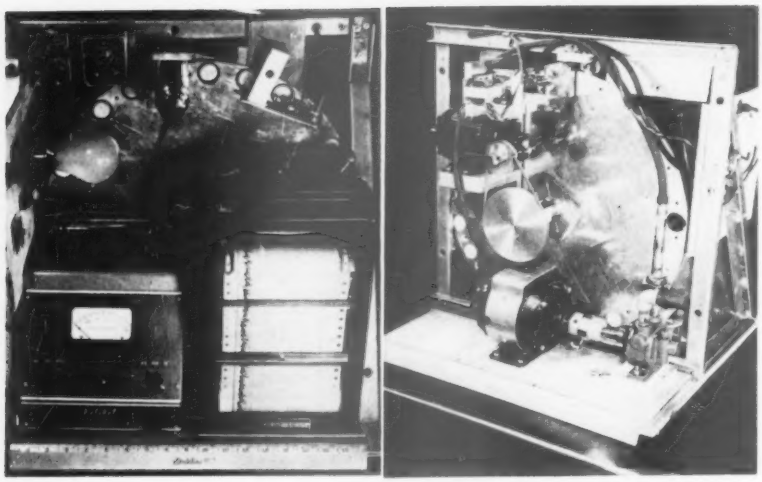

FIG. 1. Front and rear views of sampler

Automatic Sampler, Recorder

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Public Health Service
Department of Health, Education, and Welfare
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Several automatic air samplers that have been described (*1–4*) collect the sample on a continuous tape with the possibility of cross-contamination or loss of material when the tape is wound on the spool. To obtain individual samples, it is necessary to cut the tape, and some difficulty may be encountered identifying them. An instrument that automatically collects individual samples would appear, therefore, to have many practical applications.

A portable instrument is described for collecting airborne contaminants that has the following features: 24 individual samples can be collected on various types of filter media for sampling periods of 15 min to 6 hr. Immediately after collection, radioactivity is automatically determined by means of an end-window G-M tube, counting-rate meter, and recording d-c milliammeter. By omitting the counting-rate meter and recorder, the instrument can be used in atmospheric-pollution surveys and for collecting dust and fume samples in an industrial plant. Dust counts and particle-size determinations of airborne particulates can be made by substituting membrane filters for the Whatman No. 41 papers used.

The automatic sampler is housed in an aluminum cabinet, 20 × 18 × 20 in. high. Interior components are arranged as shown in Fig. 1. The electric wiring and functional diagrams are shown in Figs. 2 and 3.

Air is drawn through a sampling port located on top of the cabinet by a No. 25 Leiman Bros. vacuum pump. A constant-flow orifice was made by a No. 53 drilled hole in a circle of aluminum cut to fit a $\frac{3}{8}$-in. pipe union. This was inserted between the pump and sampling head and provides a constant flow of 0.5 ft³/min through the 1-in. effective diameter Whatman No. 41 filter paper. Twenty-four $1\frac{1}{4}$-in.-diameter filter papers are inserted in holes cut in the $17\frac{1}{2}$-in.-diameter aluminum turntable. Goodyear, hydraulic packing, $1\frac{1}{4}$-in. "O" rings are used to hold the filters in the counterbored holes.

A simple push button initiates the time cycle for the first sample, after which the interval timer and the delay timer actuate the turntable motor to move the next clean filter into place between the suction head and air inlet (Industrial Timer Corp. CM-9 interval timer and SF-15 delay timer). Twenty-four $\frac{3}{16}$-in. countersunk holes were drilled on the underside of the turntable. A pin attached to the solenoid-suction head assembly locks the turntable in place. A soft-rubber gasket attached to the open end of the suction head forms an air-tight seal against the turntable.

An end-window G-M tube of 1.4 mg/cm² window density is mounted on the left of the air-inlet tube in such a position that at the end of a sampling cycle, the turntable rotates the paper into position under the tube. G-M

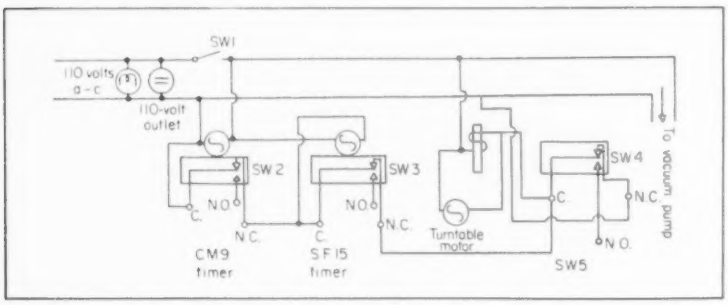

FIG. 2. Wiring diagram of sampler

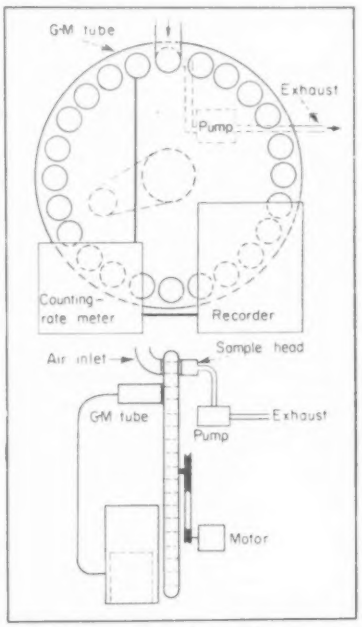

FIG. 3. Sampling and recording arrangement

tube pulses are fed into a Keleket K-900 counting-rate meter. Output from this is fed into a portable Esterline-Angus model AW variable-speed d-c milliammeter recorder. In the present model, the continuously operating detector determines activity and indicates the decay rate of the material (in the case of short-half-life activity). A third electric timer would permit operating the counting-rate circuit for any period up to the maximum sampling time and thus prolong the life of the G-M tube. The present type of Esterline-Angus recorder could also be modified to operate intermittently.

Other filter types, e.g., CWS-6, Hollingsworth and Vose, and membrane filters, have been reported to approach 100% collection efficiency. A slight modification of the instrument would be required for membrane filters. A circle of 200-mesh copper screen should be placed in the turntable to support the fragile membrane filter.

The estimated cost of components is $1,500 with the Esterline-Angus recorder and counting-rate meter being the two most costly items.

The instrument described has several disadvantages, among which are size and weight (100 pounds); however, except for the timers, the components used were available in the laboratory. Suggested modifications include the addition of a scintillation probe and suitable counting-rate circuit.

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Electroplating Technique for Tl^{204}

By A. VAN CLEVE and F. D. McDONOUGH

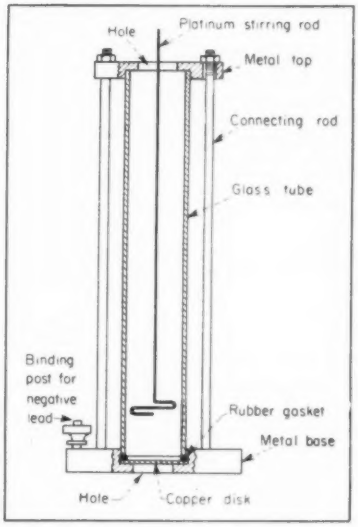
Signal Corps Engineering Laboratory
Fort Monmouth, New Jersey

A uniform high-activity beta-ray source was required for a study of phosphor luminescence. Thallium-204 appeared to have the desired characteristics (pure 0.87-Mev beta emitter, 3.5-yr half-life).

Seven millicuries were obtained from Oak Ridge National Laboratory as metallic thallium. Since the amount of thallium was so small, it was decided to plate it onto a copper disk.

The activity was dissolved in nitric acid and diluted to 100 ml. A 21-ml aliquot was adjusted to *p*H 12 with ammonium hydroxide. Hydrogen sulfide was bubbled through the solution to precipitate thallium sulfide. The supernatent liquid was again adjusted to *p*H 12, and hydrogen sulfide was passed through the solution to assure complete precipitation. Absence of residual activity in the filtrate indicated that all the thallium had been precipitated.

The precipitate was washed with ammonium hydroxide, dissolved in 20% perchloric acid, filtered into a 25-ml volumetric flask, and made up to volume. The plating bath, maintained at *p*H 2, consisted of the thallium perchlorate solution, 10 ml of carbolic acid, and 5 ml of 0.1*N* peptone to prevent polarization at the anode.



ELECTROPLATING apparatus

The first trials were run in a standard plating cell, using a platinum-wire anode. Suspending the copper disk by an alligator clip produced erratic results because of poor electrical contact. When a wire was soldered to the back of the disk, the plating process was affected by solder leaching into the solution. Attempts to cover the solder with lacquer or clear acrylic plastic were unsuccessful. The conclusion was that only the front surface of the copper disk could be in the plating bath. A plating cell made by Tracerlab, Inc., was modified to take a 1-in.-diameter disk (see illustration). The original glass tube was replaced by a larger, 1-in. i.d. tube. A flanged metal cap ring over the top of the tube is held in place by two long bolts fastened to the base. The anode connection to the solution, a piece of platinum wire, is mounted in the chuck of a stirring motor set at 100 rpm, and the power supply lead is clipped to the motor frame.

Before assembly, the disk was polished with fine steel wool, washed in an alkaline cleaner, then in a detergent, and rinsed with distilled water. Current and voltage were read with a 0–100 ma ammeter and a 0–5 volt voltmeter, respectively. The output current was controlled by a variable transformer. The Tl^{204} was plated for 30 min at a current of 5–10 ma. The resulting plate was smooth and adherent, although the vortex created by the stirrer left a lightly plated spot in the center of the disk, which did not affect its usefulness. The surface changed from grey to black when exposed to the air. A thin film of clear acrylic plastic was sprayed on this surface.

Source activity was counted with a Berkeley scaler and an end-window G-M tube in a variable-geometry holder. It was necessary to use an aluminum absorber to reduce the counting rate to a value within the resolving time of the counting setup. The plated disk gave a raw count of 400,000 cpm on the bottom holder shelf. With a 1.1% geometry, and considering the aluminum absorber, the corrected count was 3×10^7 cpm. The calculated activity of the source was 890 mc; the original total activity of the plating bath was 1,050 mc. There was, therefore, a slight activity loss to the glass-tube walls and during bath transfer. Owing to the difficulties in obtaining a calibrated beta source with the same energy as radiothallium, these calculations must be viewed only in a semi-quantitative manner.

This plating method is safe, practical and requires only a small amount of plating solution to obtain the desired results.

END

NUCLEAR ENGINEERING

Ocean Disposal of Radioactive Waste

Techniques for disposal of both packaged and free radioactive wastes into the ocean have been recommended by the National Bureau of Standards' subcommittee of waste disposal and decontamination.* Both types should be dumped in water at least 6,000 ft deep, but no specific sites are recommended. Waste packages should have minimum densities of 1.2 gm/cm.^{3} Uncontained wastes should be in a form that will sink, with liquids having densities of at least 1.1 gm/cm.^{3} Pipeline disposal is considered undesirable. Records listing isotope, amount, method of disposal, locality, and date, should be kept.

Enclosed wastes. Containers should be of steel and concrete—the lowest-priced materials fulfilling requirements that: 1, package reaches ocean bottom without appreciable loss of contents; 2, package specific gravity is at least 1.2; 3, package has sufficient shielding to limit personnel exposure during handling; and 4, size and shape facilitate handling. Common shapes, such as 55-gal steel drums and standard concrete burial vaults, have advantages.

Two suggested packaging methods are: 1, pour several inches of concrete into bottom of steel drum, add radioactive material to within few inches of top, then pour concrete around and over contents; or 2, place radioactive material in a drum that then is encased in concrete in a larger drum.

Rods and heavy woven wire might be used for reinforcement to prevent rapid loss of contents if package ruptures. It should also prevent floatable objects from separating from the concrete.

Since hydrostatic sea pressure increases by about 1 atmosphere every 3.3 ft, packages should be free of voids and large volumes of compressible materials. If such material is included, there probably should be a means of equalizing pressure. A tube from the outside, crimped shut at the inner end, serves this purpose. Permanent labels, giving the organization's name, date, most hazardous isotope and activity level might be desirable, in addition to the labels presently required.

Bulk wastes. Bulk disposal has many advantages in handling large volumes of low intensity. Safety measures in handling will set limits on the radiation levels of bulk-discharged materials. Dumping should be away from population centers and fishing activities. Deep ocean, where there is a small amount of plankton, is preferred. Solids that will sink, such as dense briquettes, pellets, or beads, are well suited to sea disposal and are easily handled.

Liquid wastes that will mix with water also can be discharged at sea, but mixing and dilution should be accelerated. Immediate dilution factors of 1–10,000 can be obtained by proper discharge. As long as the specific gravity is greater than 1.1 and the liquid is completely miscible with water, whether or not the isotope remains in solution or precipitates is not a major factor.

Conclusions. Public relations is an important factor in radioactive-waste disposal into the ocean. Any decline in fish catches might be attributed to waste dumping. Even international incidents could result. Thus, any disposal operation should be entirely justifiable in the light of existing knowledge. Advance publicity might help avoid unfavorable reactions.

Since sea burial of isotopes is final, it should be used only for materials with no foreseeable future use—there is no way of correcting ill-advised or dangerous disposals.

Accidental hazards best can be avoided by procedures that effectively do not alter accessible portions of the ocean. Precautions must be taken so that there will be no contact by unknowing individuals. The probable life of containers is short compared to the half-life of some isotopes.

Presently, there is no international regulation of disposal areas, maximum limits, and records. Such authority should be designated.

* NBS Handbook 58 (U. S. Department of Commerce, Washington, D. C., 1954).

Heterogeneous Power Reactors

W. H. ZINN, director, Argonne National Laboratory, presented the material on which this article is based before the 27th International Congress of Industrial Chemistry, Brussels, Belgium, Sept. 14, 1954

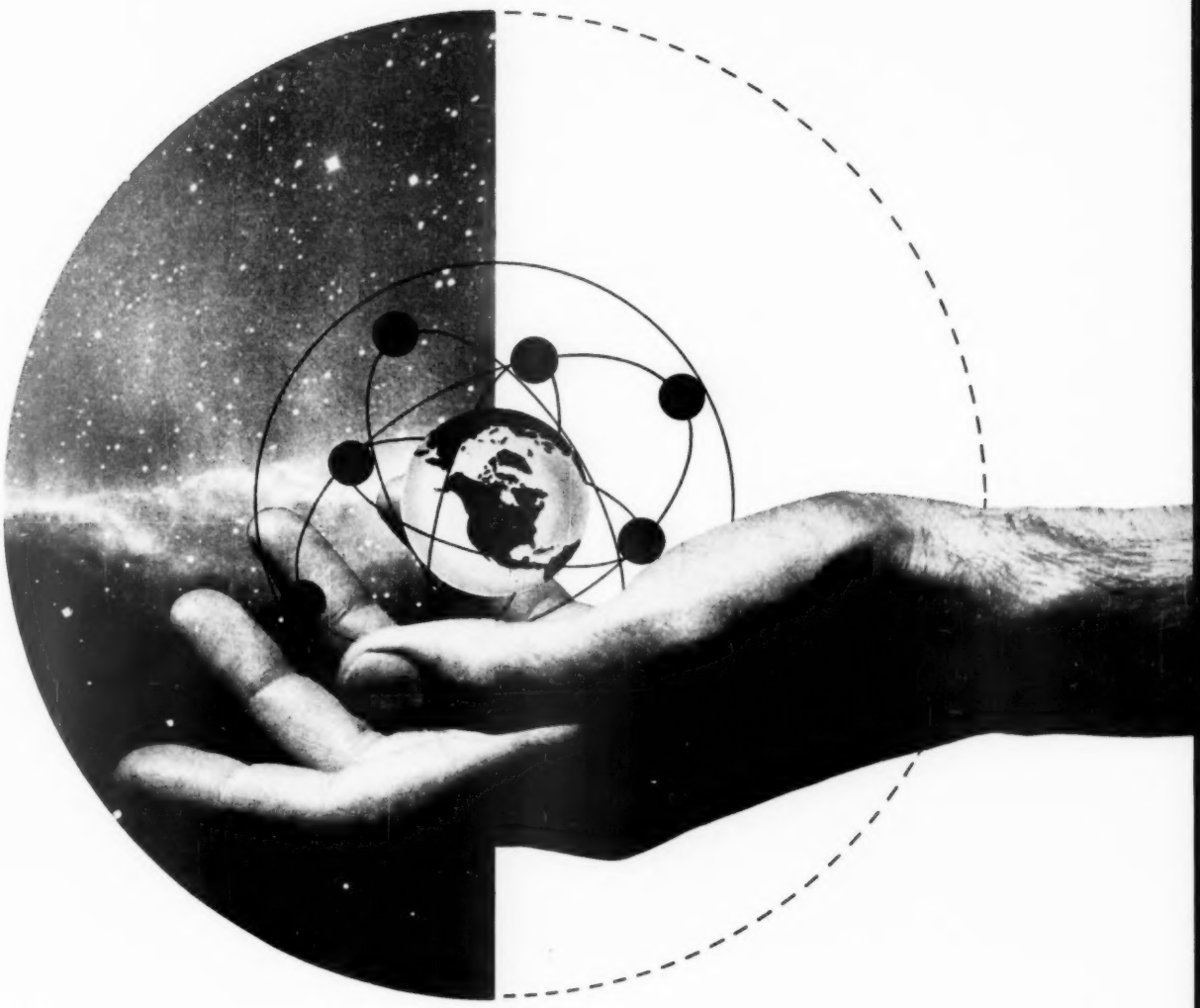
Advantages of heterogeneous reactors for power are considered here. Only reactors cooled with pressurized water or sodium are covered—although gas cooling has some advantages, the presumed difficulty of achieving high power capacity has limited U. S. interest in gas-cooled reactors.

Heterogeneous vs homogeneous. Heterogeneous reactors of substantial capacity have been in operation for more than 10 years. There have been operating problems, but altogether the experience has been good. Thus it seems that large-scale heterogeneous power reactors are practical and reliable. No large-scale homogeneous reactors are known—only after such experience has been gained will it be profitable to compare the merits of homogeneous and heterogeneous systems. It is encouraging to know that plans are going forward for rapid scale-up in the capacity of homogeneous reactors.

Pressurized water. The general features of pressurized water power reactors are familiar. The principal aspect is the high pressure under which the water must be circulated so as to reach a steam pressure permitting efficient generation of electricity; 2,000 lb/in^2 is customary.

In large-scale plants, the high pressure will create problems. The reactor pressure vessel becomes a major engineering feat when it is large and must remain in service for about 20 years without detailed inspection.

Boiling water. The boiling-water concept visualized by Argonne National Laboratory is an alternate ver-



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sion of a water reactor. It avoids some of the most costly items, and thus has the greatest hope of making early competitive power. The reactor and piping layout are extremely simple (NU, July '54, p. 43).

Despite fluctuations in moderator density caused by boiling, operation is smooth and satisfactory. This is understandable when it is realized that practical boiling reactors will have only about 20% voids in the moderator—and only the fluctuation in this void density affects reactivity. Although the steam will be "wet," 25% efficiencies and long life are attainable.

Boiling-water reactors bring about dollar savings because of the following design advantages over more conventional circulating-water reactors: 1, no steam generator is needed; 2, pumping requirements are reduced by a factor of 10—water is pumped only in returning from condenser to core; 3, pressure vessel is designed for a lower pressure—if 500 lb/in² steam is to be delivered to the turbine, the reactor vessel operates at 500 lb/in², not at 2,000 lb/in² to prevent boiling; 4, fuel-element corrosion is decreased because there is no separate steam generator to require a large temperature differential; 5, less shielding is required on the piping system outside the reactor vessel because steam velocities are high and, for the same power, the pipes contain relatively little activated water.

As disadvantages or unknowns, boiling reactors presently must accept the following: 1, more experience with the stability problem is needed, especially in a complete power plant; 2, slightly radioactive steam will enter the turbine—degree of difficulty depends on activated impurities in the steam, and thus the whole matter of corrosion and erosion in the primary circuit is of utmost importance; 3, attainable power density may be too low for competitive power application, although experiments on void density created by steam in a simulated reactor suggest that 20 kw/liter may be attainable (higher values are not ruled out).

Fuel is either natural uranium or slightly enriched uranium, depending on the choice of heavy or light water (NU, June '54, p. 69). It is assumed that fuel cost can be reduced to an acceptably low value by leaving the fuel in the reactor for a long time. Just how high burnup can be will depend on either radiation damage or loss of reactivity. Because of the difficulty of manufacturing fuel elements for water-cooled reactors once the fuel contains plutonium, reprocessing is not contemplated.

With the modest specific powers postulated for boiling reactors, burnup of 1% means a number of years' exposure. In turn, a very heavy burden is placed on the integrity of the fuel-element protective jacket and its corrosion resistance. When all problems of stability and turbine maintenance have been resolved, the problem of fuel-element durability is likely to remain. The incompatibility of uranium and hot water poses the deepest fundamental problem for the reactor designer and encourages him to look to either a homogeneous or nonaqueous reactor.

Sodium cooling. A Na-cooled reactor involves a primary Na circuit, and usually an intermediate Na or NaK circuit, in addition to the steam system. Components are more complicated and expensive than for a boiling-water reactor. Compensating factors that make Na-cooling well worth further development are: 1, no pressurization is required—only an inert gas atmosphere of 2–5 lb/in² over free liquid surfaces in the tanks; 2, high temperatures permit efficiencies over 30%—corrosion data indicate that exit temperatures to 1,100° F are possible; 3, no critical situation exists for uranium corrosion with hot Na; 4, spent fuel can be reprocessed more easily—the jacketing problem is not as severe for sodium reactors as for water-cooled reactors.

Conclusions. The long burnup method will not be used long once a nuclear-power industry is established. The supply of fissionable and fertile materials, although perhaps large, will not permit a 99% fuel discard as contaminated waste. Heterogeneous breeder reactors will be first to reprocess fuel since for them it is a necessity. Nonbreeder types of power reactors will follow along and will be fueled with plutonium or U^{233}.

The practicability of manufacturing strongly alpha-active fuel material into fuel elements will be determined largely by the complexity of the fuel element itself. In future competition among reactor types, the ones with the easiest to construct fuel element designs may emerge superior. Perhaps this can be accomplished where sodium is the coolant. We may be weighing the advantage of an extremely simple reactor plant and a difficult-to-manufacture fuel element against a more complicated reactor system and an easier-to-manufacture fuel element.

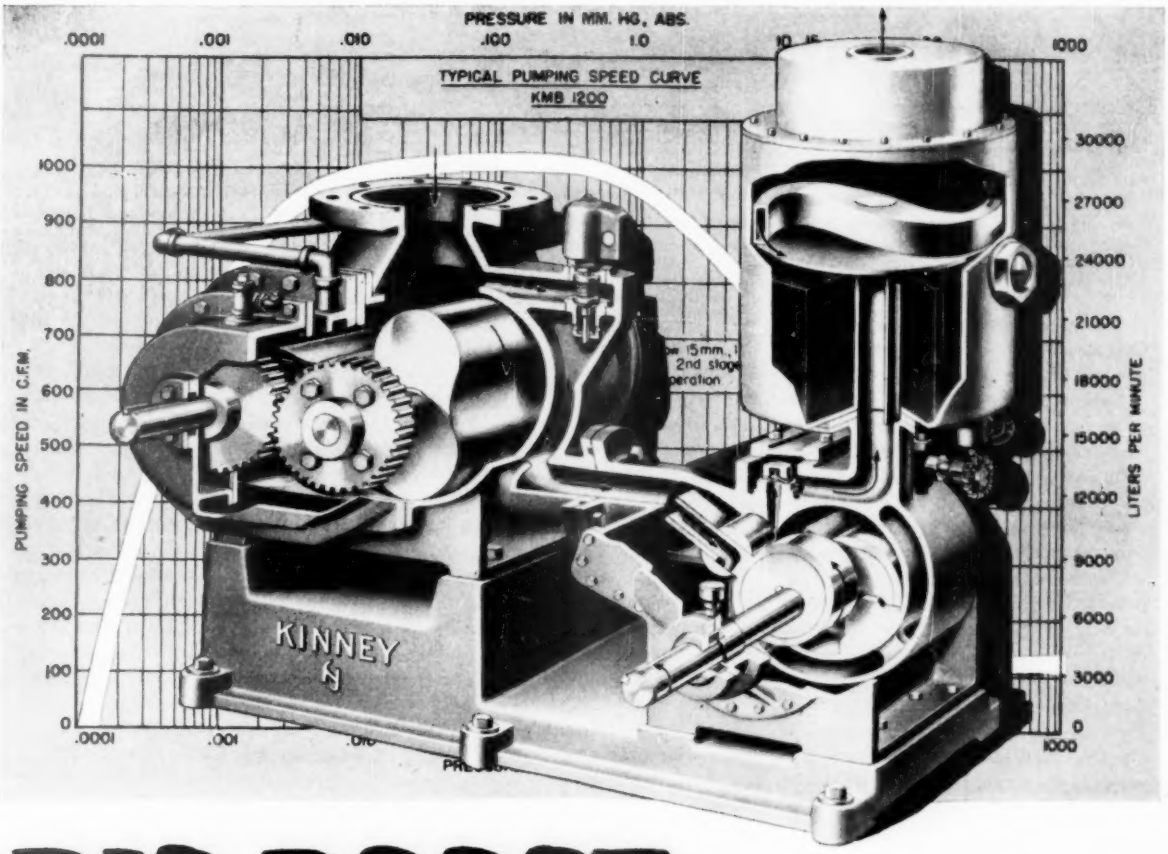
NUCLEAR POWER

• **D_2O leak detector** that is fail-safe and can be functionally tested from the control panel has been developed at the duPont-operated Savannah River Laboratory for use on the process development (PDP) and standard (SP) pile moderator circuits. The multipoint system, which can be built without machine shop work, has detecting elements made by closing a small brass hinge over a filter-paper-wrapped brass strip. Leaking water absorbed by paper radically reduces paper's electrical resistance; current fires a thyratron and lights neon bulb in its plate circuit. Device is reset by replacing filter paper.

• **Location** of nuclear power plants will be dictated largely by proximity to load and water supply, according to T. G. LeClair of Commonwealth Edison Co. Transmission costs as high as 3 mills/kwh for each 100 miles require that most power plants be located reasonably near load center (most power used in U. S. is transmitted less than 25 miles). Because early nuclear power plants will probably use more than the 400–500 lb of cooling water per kwh used by modern steam-plant condensers, proximity to water supply probably would be desirable.

• **Molybdenum,** in its commercially pure form, is embrittled to such an extent after reactor irradiation to 1.9–5.9 × 10^{20} thermal neutrons/cm² that it is unsafe for use in load-carrying reactor components at low temperatures, according to tests by Knolls Atomic Power Laboratory.

• **Fluor Corporation** has carried design of an MTR-like light-water cooled and moderated dual-purpose reactor system to the point where it feels that "competitive nuclear power is possible now" if AEC sets "reasonable" prices for U^{235} and Pu. The complete plant's estimated capital cost of $183/kw (net—and this doesn't include fuel cost) gives fixed charges of 3.2 mills/kwh, based on a 15% amortization rate. Most of the estimated equipment costs are based on vendors' firm quotations, and about $250,000 is allowed for core development. Power cost of 7 mills/kwh is estimated if AEC charges $20/gm for U^{235} and pays $28/gm for Pu during the 7-yr amortization period and $8/gm after that. Burnup is assumed to be 1,500 Mwd/ton; load factor, 85%; power level is in the range 60—300 Mw but exact level has not been revealed.



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BOOKS

Metallurgy of the Rarer Metals: 2, Zirconium

By G. L. MILLER (Academic Press, Inc., New York, 1954, xviii + 382 pages, $7.50). Reviewed by E. C. MILLER, Metallurgy Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

A sizable zirconium industry has been in existence for many years. The zirconium produced has been used, largely in compound form, in refractories and vitreous enamels and also, to a lesser extent, as a nonductile metal or alloy and as a minor constituent in the alloys of other metals. In recent years, however, there has been an expanding production of zirconium metal in ductile form because of its actual and potential uses as a structural material for nuclear reactors. Many advances in zirconium technology have resulted from the production and use of this ductile form, and the literature devoted to this technology has expanded rapidly. A considerable need has developed, therefore, for a critical review of the literature on zirconium and for a compilation of the most significant information into a single volume. This book admirably supplies that need.

The first chapter covers the occurrences and world resources of zirconium, which, despite the title series, "Metallurgy of the Rarer Metals," of which this volume is a part, ranks as the eleventh in abundance among the elements in the crust of the earth. The principal ore deposits are in the United States and Australia, but there are large reserves in Brazil, India, and some other locations.

The book contains a review of specific uses of zirconium in alloys and refractories and in the metallic form in nuclear reactors, corrosion-resistant equipment, electronics, and surgery.

The methods of extracting zirconium from its ores and preparing pure compounds are covered in some detail. Particular attention is given to the separation of zirconium from the approximately 2% hafnium with which it is apparently always associated in nature. The hafnium, because of its high neutron-absorption cross section, must be removed to allow the use of zirconium in nuclear reactors.

A large part of the new technology of zirconium relates to the production of the metal, and the book contains a review of the early development of production methods, descriptions of the present-day van Arkel and Kroll processes, and a particularly excellent summary of the new methods and modifications of current methods, which are being investigated with the objective of producing a better product at a lower price. These methods include the combination of the purification and reduction steps; use of a mixed sodium-and-magnesium reducing agent; continuous reduction; use of hydrogen as a reducing agent; arc dissociation of halides; oxide reduction with calcium and magnesium; disproportionation of lower halides; calcium reduction; and electrodeposition.

Several chapters cover a summary of the data contained in the literature on the properties of zirconium and its alloys: structure and physical properties of the metal; mechanical properties of the metal and its alloys; and chemical properties, including gas reactions and corrosion behavior.

The available literature on zirconium alloys is reviewed, including that pertaining to theoretical considerations as well as the quantitative investigations of binary systems.

The unusual properties of zirconium —high melting point and extreme reactivity at elevated temperatures— have required the development of unusual precautions and methods for melting and fabricating the metal to preserve its purity and ductility. These are discussed in considerable detail.

The final chapters deal with the powder metallurgy of the metal and with the production, properties, and use of a number of special compounds of zirconium, the nitride, carbide, boride, and silicide, whose properties are essentially metallic and hold promise as materials for high-temperature applications.

This is one of the best publications on zirconium to appear in the unclassified field, and it is doubtful that a more accurate or critical summary of the subject could be produced without access to the classified literature. For the information of those interested in the nuclear properties of zirconium, the presently accepted best value for the thermal-neutron absorption cross section is 0.18 ± 0.02 barns (AECU-2040), rather than the value of 0.4 barns quoted by the author on p. 113.

Noise

By ALDERT VAN DER ZIEL (Prentice-Hall, Inc., New York, 1954, xi + 450 pages, $10.35). Reviewed by S. N. VAN VOORHIS, Massachusetts Institute of Technology, Lincoln Laboratory, Lexington, Massachusetts.

This book is concerned primarily with the undesired portion of the output signal of a vacuum tube or other device, which arises from fluctuation phenomena of one sort or another. Application of the term "noise" to these phenomena is well established by usage and has an origin obvious to anyone who has ever connected a loudspeaker to the output of a high-gain amplifier. The book is concerned for the most part with noise phenomena in vacuum-tube circuits covering the entire range of frequencies from very low up to the microwave range. There is, in addition, a fair amount of discussion of the properties of transistors and other solid-state devices.

The study of fluctuation phenomena and their role as a limit to the possible precision of any measurement process has been a comparatively recent development, starting toward the beginning of the present century. It is notable that many of the workers in this field have come from the Netherlands. Perhaps one may draw some connection between the skill and patience required to conduct measurements at high precision and a study of the limitations of such measurements. Be this as it may, the study has proceeded until the subject is now on a fairly well understood footing. This present book is a worthy member of the line. It is a thorough-going treatment of the subject and definitely is not popularized for the lay reader.

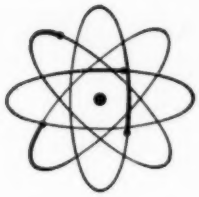
Chapter 1 is introductory in nature, laying the groundwork for the general nature of the topics to be considered and introducing certain fundamentals of probability theory, correlation, Fourier analysis, and complex notation. Chapter 2 introduces the topic of thermal noise, as given by Nyquist's theorem, and goes on to generalize this for the case of circuits not at a uniform temperature. Further applications are then noted on the noise properties of various microphones. Chapter 3 continues the study of noise, bringing in the shot effect and Schottky's theorem and showing the interrelationships between these and Nyquist's theorem.

The concepts of noise figure of a circuit and equivalent noise resistance of a vacuum tube are introduced. Expressions are given for the noise figure of networks in cascade. Finally, the influence of these topics on radio-receiver design is considered. Chapter 4 is concerned with experimental methods used in noise measurement. Amplifiers and detectors are first taken up, followed by the various sources of noise, including temperature-limited diodes and fluorescent or gas-discharge noise sources. Various measurement procedures are given in fair detail.

Chapter 5 begins a detailed consideration of noise phenomena in vacuum tubes. It is concerned with noise effects at low frequencies, that is, below perhaps 5 Mc/sec. First, two-electrode tubes or diodes are considered; both the condition of temperature limitation and of space-charge limitation are studied. Next, the case of triodes is considered. Following this, the topic of partition noise and its influence on the noise properties of multigrid tubes is considered. Finally, the modifications of these results due to the phenomena of secondary-electron emission are noted. Chapter 6 continues the topic of tube noise up into the region of high frequencies. It is concerned with diodes and triodes of the conventional type. Chapter 7, entitled *Practical Low Noise Circuits*, has to do with the application of the fundamental phenomena just studied to the design, construction, and adjustment of circuits having low noise properties. The various types of triode circuits, grounded cathode, grounded grid, and grounded plate, as well as combinations of these, are considered.

In chapter 8, the topic of *Semiconductors and Their Noise Properties* is introduced. The chapter begins with a brief resume of the pertinent parts of solid-state theory and goes on to a description of the construction, general properties and use of transistors. The phenomenon of excess noise is then described as it occurs in semiconductors, in contacts or carbon microphones, in carbon resistors and thin metal layers. The existence of a $1/f$ law for this noise as well as for flicker noise in vacuum tubes is pointed out. A possible explanation of this $1/f$ law is also given. Here the author has not hesitated to plunge into a part of the field that is still under very active work, running the danger thereby of having generally accepted ideas changed on him in comparatively short time.

Chapter 9 is concerned with the noise



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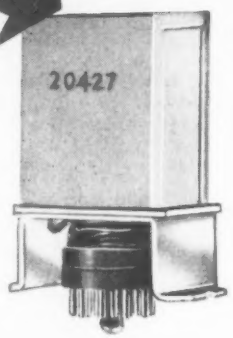
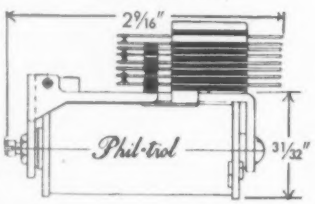


PLUG-IN — DUST COVERED TYPE 6QA — (Quick Acting)



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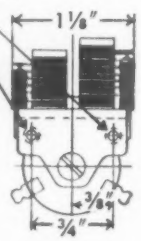

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properties of mixer tubes and circuits. The various types of specialized vacuum tubes for mixer service are first considered, after which diode mixers, both vacuum tube and crystal, are studied. Questions of image frequency response and of noise contributed by local oscillators are then touched upon. Chapter 10 takes up in a rigorous manner the effect of feedback on the noise property of circuits. Chapters 11 and 12 are mathematical in nature, covering, respectively, certain topics in statistical methods and methods of Fourier analysis of fluctuating quantities. Chapter 13 then goes on to a study of noise in detector circuits, including quadratic detectors, linear detectors, and phase sensitive detectors. In Chapter 14, the behavior of vacuum tubes is attacked with yet another degree of rigor, taking advantage of all the previous developments. The Llewellyn-Peterson equations and the theory of Bakker and deVries are then introduced.

Chapter 15 then takes up the subject of space-charge waves in electron beams and indicates how the noise property of various velocity-modulation tubes may be attacked. Finally, Chapter 16 gives some fundamental considerations concerning noise in physical instruments.

In summary, it may be said that this seems to be a very worthwhile book. It covers a quite wide range of topics and there certainly has been no effort to spare the rigor. The reader who is not a specialist in the field may find the going somewhat tough at times. If, however, he gets through, he will be rewarded by a thorough knowledge of the subject. Many of the measurements cited in the book are made on European types of tubes. If this were a cookbook type of text aiming to give specific details for the construction of definite circuits, this feature would be a disadvantage. However, as indicated above, the approach is one of going to fundamentals, which are the same no matter what the label on the vacuum tube. The book should prove to be a useful one.

BOOKS RECEIVED

Feedback Control Systems, by Gilbert H. Fett, Prentice-Hall, Inc., New York, 1954, ix + 361 pages, $10.00. *(To be reviewed.)*

Biological Effects of External Radiation (National Nuclear Energy Series vi-2), edited by Henry A. Blair,

McGraw-Hill Book Co., Inc., New York, 1954, xvii + 508 pages, $7.00. (*To be reviewed.*)

Atomic Energy and its Applications, by J. M. A. Lenihan, Pitman Publishing Corp., New York, 1954, xiii + 265 pages, $4.00. (*To be reviewed.*)

Rare Metals Handbook, edited by Clifford A. Hampel, Reinhold Publishing Corp., New York, 1954, xiii + 657 pages, $12.00. (*To be reviewed.*)

The Microphysical World, by William Wilson, Philosophical Library, New York, 1954, vii + 216 pages, $3.75. Written for the layman, this book describes the development and present state of knowledge of microphysical phenomena, principally relating to the molecule and atom and their constituent particles.

ALSO OF NOTE

Atomic Energy—A Survey. Published for the Atomic Scientists' Association, J. Rotblat, Editor, this 71-page book consists of lectures given at the University of London in 1954. The lectures are: *Atomic Energy Research at Harwell* (J. D. Cockcroft), *Atomic Weapons* (O. R. Frisch), *Power from Atomic Energy* (F. E. Simon), *Radiation Hazards of Atomic Energy* (J. F. Loutit), *Medical Uses of Atomic Energy* (E. E. Pochin), and *Atomic Energy and Moral Issues* (K. Lonsdale). *Taylor & Francis, Ltd., Red Lion Court, Fleet St., London, E.C.4, $0.70 (paperbound), $1.00 (clothbound).*

The Nation Looks at Its Resources. This report covers the Mid-Century Conference on Resources for the Future, held in Washington, D. C., Dec. '53, which explored factors underlying the mounting pressure on our natural resources. Problems discussed were: land utilization, water resources, nonfuel materials, energy (including atomic energy), world resources, and research. *Resources for the Future, Inc., 1145 19th St., N. W., Washington 6, D. C., $5.00.*

Correlation Chart of Uranium Bearing Minerals. This 52 × 32 in. chart, containing over 160 uranium-bearing minerals, is divided vertically into chemical-radical columns and horizontally into chemical-element bands. Identification characteristics are given for each mineral. *Colorado School of Mines Research Foundation, Inc., Golden, Colo., $5.00.*

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TECHNICAL ADVANCES

New Tracer: Aluminum-26

Tracers are now available for every element. Aluminum, which has but one stable isotope, Al^{27}, was long thought to have only short-lived unstable isotopes too, making Al inaccessible for tracer studies. Now Carnegie Tech radiochemists, led by Truman Kohman, have uncovered the true ground state of cyclotron-produced Al^{26} and find that it has a half-life of about 10^6 yr and emits positrons of approximately 1 Mev energy followed by a 1.83-Mev gamma ray. Extent of practical tracer use will depend on quantities of Al^{26} that can be produced.

Cold Neutrons and Lattice Vibrations

New understanding of the solid state of matter may result from an experiment on the thermal motions of atoms in a solid that is just getting under way at Brookhaven. Cold neutrons ($E = 0.001$ ev, $\lambda \cong 10$ Å) will be directed at a single-crystal sample and, being so slow, will gain energy in collisions with the vibrating atoms of the crystal lattice. The energy spectrum and angular distribution of the emergent neutrons will therefore reflect the energy distribution of the atoms in the crystal. This problem has been investigated theoretically starting with the work of Einstein and Debye at the turn of the century, but past experimental approaches have not been as direct as the present one.

"Molecular Sieves"

"Molecular Sieves," Linde Air Products' new synthetic zeolites, offer impressive adsorption properties and selection of adsorbed molecules according to size. Chemically the zeolites are crystalline hydrous silicates quite similar to many natural clays and feldspars. When the water of hydration is driven off, the crystal does not collapse or rearrange; rather it remains unchanged, yielding a structure with many small (10 Å diameter) cavities connected by still smaller pores, both extremely uniform. The pores are 4 Å in diameter in one type, 5 Å in another, and only molecules that can pass through can be adsorbed. Thus molecular sieves can grade molecules according to size: for example, straight-chain hydrocarbons like *n*-hexane will be adsorbed, but not wider branched-chain isohexane, nor cyclic hydrocarbons like cyclohexane and benzene.

These new synthetic zeolites also show a marked affinity for chemically unsaturated molecules and for polar molecules. This last property helps make it an excellent dessicant that can also be used to dry organic liquids. Adsorption capacity is high at low concentrations and at high temperatures.

Storing Radiation Effects

Radiation effects are "put on ice" in a polymerization experiment that R. B. Mesrobian and coworkers from Brooklyn Polytechnic and Brookhaven are conducting. They irradiate acrylamide and related monomers with Co^{60} gamma rays at temperatures so low (−18° C) that the radicals formed are trapped. No polymerization takes place until the sample is brought to room temperature, when polymerization proceeds rapidly, heating the sample until it explodes.

Basic mechanisms are not understood. Puzzling is why samples stored at 4° C after irradiation at −18° C do not polymerize even with the passage of weeks, although irradiation at 4° C produces partial polymerization. Intriguing is the possibility of using this stored irradiation energy.

New Pulsed Neutron Source

Ion pumps, which ionize the residual gas and sweep it out in a collimated plasma discharge, have shown promise as high-vacuum pumps. Now they emerge in a new guise: Livermore researchers E. F. Martina and V. J. Ashby have taken advantage of the low pressures and high currents of ion pumps to concoct a pulsed neutron source.

The ion pump is fed deuterium gas. A 200-kv accelerating potential, provided by a pulse generator, deflects deuterium ions in the plasma onto a deuterium-loaded target inside the pump body. Neutrons are produced in the ensuing *d-d* reactions. Improvements underway, including use of the *d-t* reaction, point to 10^8 14-Mev neutrons per 10^{-9}-sec burst, 10 bursts a second, 10% energy resolution.

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Summary of Beta-Gage Process-Control Experience*

Firm and first year of use	*Type of material*	*Quantity measured*	*Previous measurement method*	*Deviation from standard*		*Continuous-contact gages*		*Frequency of*	
				Previous	*β gage*	*Ever used*	*Reason for discontinuing*	*Standardizing*	*Calibrating*
Congoleum-Nairn, 1950	Linoleum	Thickness	Spot check, dial gages	0.004 in.	0.002 in.	Yes	Roll pick-up, marked product, inaccurate	8 hr	30 min
Hood Rubber Co., 1950	Rubber-and plastic-coated fabric	Basis weight	Cut samples to measure and weigh	0.0025 in.	0.0015 in.	Yes	Roll pick-up, marked stock, unreliable	2 hr	Infrequent
Gates Rubber Co., 1950	Rubber-coated fabric	Basis weight	Condenser type gage	0.003 in.	0.001 in.†	Yes	Not accurate	20 min	7 days
Firestone Tire and Rubber Co., 1951	Rubberized fabric	Thickness	Dial type, magnetic gage	—	Quite a uniformity improvement†	Yes	Still used	30 min	7 days
A Canadian rubber co., 1952	Rubber	Thickness	Hand gage	Various	50% better	No	—	2–4 mo	24 hr
A maker of hospital supplies, 1951	Adhesive tape	Basis weight	Roller dial, sample weighing	25%	10%†	Yes	Roll pick-up	24 hr	Once each run
Bird and Son, Inc., 1951	Coatings	Weight	Roller and sample weighing	11.4%	1.4%	No	—	8 hr	At product changes
Canadian Industries, Ltd., 1953	Vinyl plastics	Thickness, weight	Hand gage, sample weighing	10%	5%	No	—	about 3 mo	At product changes
The Formica Co., 1952	Resin impregnated paper	Resin % in paper	Sample weighing	2.5%	1.5%†	No	—	30 min	7 days
Strathmore Paper Co., 1951	Paper	Basis weight	Sample weighing	5%	3%	No	—	4 hr	3 weeks
A specialty paper manufacturer, 1951	Paper	Basis weight	Sample weighing, caliper trim	Indefinite	Less waste	Yes	Air type-plugged, magnetic type-inaccurate	30 min	½–3 hr
Eastern Corp., 1953	Paper	Basis weight	Sample weighing	—	Less waste†	No	—	4 hr	As necessary
Carborundum Co., 1953	Coated abrasive products	Basis weight	Sample weighing	5%	2%†	No	—	30 min	—

* Compiled by N. S. Foster of Congoleum-Nairn Inc., and presented at the Tracerlab Symposium on Applications of Radioisotopes in Industry, October, 1954.

† These firms are using β-gage as basis of automatic process-control system.

Beta-Gage Performance

Process-control experiences with beta gages are presented in the table on this page. Quality-control improvement has been consistently obtained by using these gages. Deviation from standard has decreased an average of over 56% among the firms reporting figures; one company decreased its product's deviation by 87%. Intervals between standardizing and calibrating vary widely, depending on whether gage does this automatically, and product.

Radioisotope Versatility

Versatility of radioisotopes was emphasized at a panel recently held by the National Industrial Conference Board. The ways in which the following companies are profitably using

radioactive material in their routine work were presented.

Hercules Powder Co. uses isotopic-dilution analysis for penta-erythritol. Method is based on specific activity measurements of the C^{14}-labeled compound.

John Labatt, Ltd. (Canada) makes wide use of radioisotopes: pipe-line weld inspection; steam-jacket corrosion inspection; storage-tank level indicator; and as source in beer pasturization study. Firm has used isotopes for locating leak in concrete-encased radiant heating system.

Dominion Rubber Co. (Canada) uses thickness gages because rubber is difficult to measure accurately by contacting methods. Mere physical presence of a thickness recorder greatly improves operator performance.

Proctor and Gamble Co. analyzes for triphosphate and pyrophosphate by isotopic dilution, uses C^{14} for detergent wash tests, and detects detergents' reactions with cloth by using isotopes. Another use is liquid-level gage in high-pressure container.

Aluminum Company of America has received about 82 isotope shipments for use in: Na, P, Ca, and K analysis (see page 29); cutting-tool wear investigation; metal flow tracer during extrusion; effects of Hg on Al corrosion; mechanism of anodic oxidation; autoradiography for locating Cr and Na in Al alloys; and in lubrication additive evaluation.

Ontario Paper Co. Ltd. (Canada) has traced material flow on a paper-making machine using tagged fibers. Thickness-gage and laboratory measurements along paper profile have been compared. Mechanisms of pulping are now being studied with S^{35} tracer. Gamma gages are used for inspecting digestors and digestor linings.

Wyandotte Chemicals Corp. uses C^{14} in testing detergents, particularly on soil redeposition studies. Methods of cleaning metal before plating have been evaluated.

Gulf Research and Development Co. used cyclotron-produced V in 1941 to follow flow in porous media. It also made an early study of well cementing. The mechanism of the Fischer-Tropsch reaction has also been investigated. The firm supplies labeled insecticides for biological work.

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DIRECT READING CHAMBERS

Obtain a roentgen reading of accumulated radiation in a space of a few seconds with direct reading pocket chambers. Used increasingly by the scientist, radiologist and technician, only this type of unit gives immediate, on-the-spot reading of exposure. It is especially suited for those working continuously with larger sources of radiation. Chambers are charged by insertion in the battery-charger unit, Model 561, shown.

FEATURES: Accuracy . . . 5% Full Scale • Hermetic Seal • Built To Military Requirements For Temperature, Accuracy, Drop-Testing • Linear Scale • Maximum Leakage...2%/24 hrs. • Energy Dependency . . . ± 10% of True Dose from 0.08 to 2.0 Mev • Size . . . ½" x 4".

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Victoreen Chambers accumulate roentgen exposure while worn. Dose or exposure is read daily on the charger-reader unit, Model 287 Minometer, and recorded. After reading the dose, the pocket chamber is readied for re-use by re-charging with the charger-reader unit.

The two-to-three week delay in obtaining readings, inherent with film badge use, is eliminated. One year's rental of film badge service for 6 persons exceeds the cost of outright purchase of a Minometer and six chambers.

MODEL	RANGE	CHAMBERS	SIZE
362	0-0.2r	POCKET CHAMBER	5½" x ½"
*239	0-0.01r	STRAY RADIATION	4½" x 2"
*208	0-0.001r	STRAY RADIATION	6¼" x 4½"

* 1/16" bakelite wall.

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Model 107	Amplifier	$545.00
Model 107P	Amplifier (includes pulse-height selector)	$595.00
Model 112	Amplifier (gain of 1000)	$350.00
Model 401	Mercury Pulse Generator	$145.00
Model 515	HV Supply (500-1500 volts)	$385.00
Model 540	HV Supply (1000-4000 volts)	$535.00

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- Counting Rates—Supplies evenly spaced pulses from 60 cps to 10,000 cps, 20,000 cps with double pulse generator. The unit also supplies pulses at approx. 3 cps which enables visual location of defective scaling stages.
- Combinations—The model 577 is so arranged that all possible combinations of the above can be obtained.

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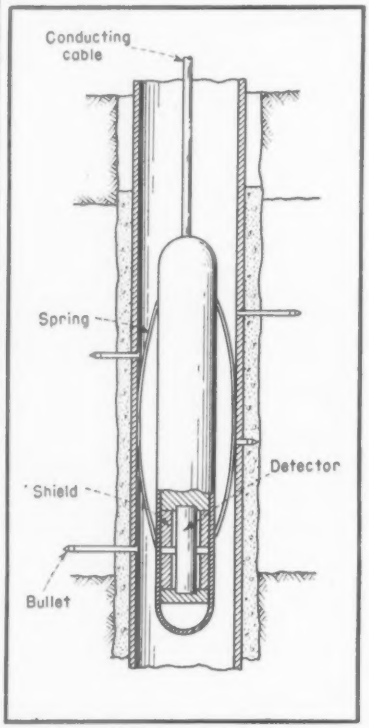
Patents



DEPTH-PENETRATION detector suspended in well

Measuring Depth Penetration of Bullets in Subsurface Formations*

Gun-perforating well casing or pipe involves firing a number of bullets through the casing wall in radial directions from the well bore and into the subsurface formation. Although the bullet's depth of penetration into the formation affects the well's productivity, its determination is on a more or less guesswork basis.

In U. S. Patent 2,685,038, Robert L. Hoss describes a method for accurately determining the depth of penetration by putting a controlled amount of radioactive material in a capsule within the projectile. The depth of penetration is then determined by measuring the radiation intensity at a point within the well bore.

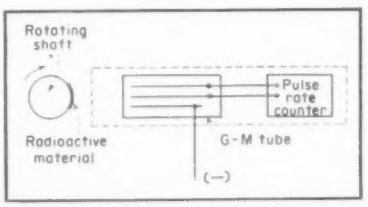
The measuring instrument is lowered into the well bore by means of a conductor cable. The instrument housing is centered by bowed springs. Mounted within the lower portion of the housing is a G-M counter or ionization chamber. To confine the radioactive emissions to a single horizontal plane, the detector is shielded by lead sleeves or collars, spaced apart to provide an annular entry slot. A recording device is located at the upper end of the conductor cable. The magnitude of the current is inversely proportional to the distance of penetration.

Alpha-Ray Tachometer*

Shaft rotation or the degree of vibration or strain of a material is measured in many cases by specially constructing shafts or moving members with projections that disturb a magnetic field or by using a mirror, light source, and photoelectric tube system.

A method developed by Herbert Friedman, described in U. S. 2,683,813, uses radioactive material to greatly decrease interference with the system under measurement. A small amount of radioactive material, e.g., polonium, immersed in a binder such as dilute collodium is painted on the object to be tested.

As an example, a G-M tube is placed opposite a rotary shaft on which is deposited the radioactive source. When the source is at the position closest to the tube, tube current is at the maximum; at the source position farthest from the tube, no energy is detected since it is blocked by the shaft. The G-M output pulses are rectified by a diode, filtered, and fed to a constant-width pulse generator, e.g., a single-shot multivibrator. An integration circuit coupled to the multivibrator



SHAFT-ROTATION counter uses G-M tube

output develops a d-c voltage equal to the average multivibrator pulse output. A d-c indicating device can be calibrated in rpm.

For good definition, a masking ele-

* Description based on abstract furnished by Melvin Nord, Registered Professional Engineer, Patent Attorney, Detroit, Mich.

ment having a series of apertures can be placed between the detector and the source. For measuring high speeds, the G-M tube is preferably operated in the proportional region.

In place of the G-M tube, a phosphor screen, e.g., zinc sulfide, can be used for alpha emitters. The light can be received directly or focused by a lense on a phototube.

To indicate strain on a flat plate or bar, several areas of radioactive material can be painted on the plate and a mask placed between the detector and plate. If under no load the radioactive areas are completely screened by the mask, a slight movement of the surface up or down brings the radioactive areas over the mask apertures.

AEC Patents

THE FOLLOWING PATENTS are available from the AEC for licensing, ordinarily on a nonexclusive, royalty-free basis. The descriptions are based on abstracts furnished by the Index of Inventions, maintained by the Government Patents Board, Washington, D. C.

Recovery of heavy water from reacted solutions thereof (2,681,883), C. F. Hiskey—Heavy water is recovered from uranyl fluoride solution by distilling heavy water in presence of uranium trioxide.

Compounds of the element americium (2,681,923), L. B. Asprey, R. A. Penneman, S. E. Stephanou—Americium of oxidation state less than six is treated in 0.3*M* perchloric acid with excess soluble peroxydisulfate, yielding oxidation state of six; insoluble sodium americyl acetate, formed by adding sodium acetate, is recovered.

Shipping container for radioactive material (2,682,352), M. B. Hawkins, E. R. Tompkins—Container can has dust-tight sealed cap to prevent escape of radioactive materials while permitting escape of gases, which may be produced during neutron treatment. Means are provided for shearing cap.

Electronic controlled pumping system (2,682,364), D. S. Schover—In toepler-type gas-pumping system, electronic means are provided for alternately evacuating and applying pressure.

Still (2,682,451), R. J. Schmidt, S. Rosenfeld—Distillation apparatus is useful in production and purification of uranium chlorides.

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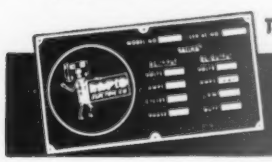

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LETTERS

Amplifiers: An Amplification

DEAR SIR:

The article titled "Trends in Nuclear Instrumentation" by Denis Taylor (NU, Oct. '54, p. 12) contains an error. On page 15 there is a discussion of the effects of high counting rate on resolution in linear amplifiers. It is correctly stated that J. E. Francis, P. R. Bell and G. G. Kelley have developed a double line amplifier to minimize the effects of high and variable counting rate. However, it is important that the first such amplifier at Oak Ridge was developed by Edward Fairstein.

The article then goes on to state that Dr. Borkowski showed some results from the double line amplifier developed by Francis, Bell and Kelley. Actually the data given were taken by Fairstein on the amplifier developed by him. Fairstein's amplifier is a very good one and he should get proper credit for it.

—P. R. BELL
Physics Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

An "Editorial" Transfer

DEAR SIR:

Concerning "A Gamma-Ray Source for Sterilizing Insects" by Darden, Maeyens, and Bushland (NU, Oct. '54, p. 60), this article appeared as though the work were all done in the biology division, Oak Ridge National Laboratory, and that Dr. Bushland had been with us but now left the division and gone to the U. S. Department of Agriculture in Kerrville, Texas. Of course, this is entirely false. This contribution was a joint effort between the biology division and the USDA conducted at long range. Dr. Bushland has been the leader in the insect work throughout working at his USDA laboratory.

—C. W. SHEPPARD
Assistant Director, Biology Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

NUCLEONICS *offers its apologies for an editorial error. The above letter sets the affiliations straight.*

ORNL Research Reactor

DEAR SIR:

I appreciated the opportunity of having my article "A High Per-

formance Research Reactor" appear as an article in the September issue of NUCLEONICS.

In the submitted article, no mention was made of the fact that a research reactor was to be constructed at Oak Ridge National Laboratory. But, contrary to the objective of the article, statements were made, under "Late News and Commentary" that the details of the new Oak Ridge Research Reactor design are given in the above mentioned article.

Since the reactor to be constructed at ORNL does not resemble the reactor design described, the statements have proved to be embarrassing to myself, the Laboratory and the AEC.

—JOSEPH P. GILL
Reactor Experimental Engineering Div.
Oak Ridge National Laboratory,
Oak Ridge, Tennessee

The following excerpt from a letter from T. E. Cole, head of the ORNL group designing the reactor for which Mr. Gill is project engineer, should clarify the situation:

"The confusion between the two reactors is understandable due to the fact that the news release on ORR came at about the same time you were working up the article written by Mr. Gill. The relationship between the two facilities is as follows: ORNL has for several years been doing preliminary design on a reactor for general research use here at the laboratory; the design Mr. Gill described at the Ann Arbor meeting represents the design as it stood during one phase of this preliminary work. The reactor described is admirably suited to basic research type work but does not meet the requirements of flexibility imposed by the widely varied programs at ORNL. The reactor we propose building at the laboratory differs considerably from the one described by Mr. Gill."

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NEWS

United Nations Gets Details of Atom Pool Proposal, Promises for Fissionable Materials; Soviet Union, India, Brazil Added to Conference Planning Group

First steps towards setting up an international agency and a 1955 conference on atomic energy were taken in the United Nations last month. In proposing implementation of the Eisenhower "pool" plan (NU, Oct. '54, p. 76), U. S. delegate Henry Cabot Lodge, Jr. outlined a broad international education and information program to be carried out in 1955.

Great Britain, France, Canada, Australia, Belgium, and South Africa joined the U. S. in submitting a resolution to call the conference and set up the agency.

Agency Proposed

Lodge emphasized that details of the agency setup would have to be worked out as it was organized. It would be a "special" agency; like ten others it would be under UN auspices but would remain autonomous. A UN Secretariat committee is studying how the agency could operate, but final plans will probably follow recommendations still to be made by the United States.

As originally proposed, the agency was to serve as a world "bank" for fissionable materials. This has been modified so that the agency would not own material but would instead serve as a "broker" through which participating nations would supply material directly to agency-sponsored projects.

Another change from Eisenhower's original proposal is the dropping of the idea that the agency would "provide abundant electrical energy in the power-starved areas of the world."

Allot Fissionable Material

The United States has allotted 220 lbs of uranium to the proposed agency; Great Britain will contribute 44 lbs. The total 264 lbs may permit up to 33 new reactors to be added to the world's quest for constructive nuclear progress.

Although the contributed fuel's degree of enrichment has not been revealed, the fact that 2.5–30 tons of unenriched fuel is required (see table) for just one reactor (depending on whether moderator is D_2O, water, or graphite) makes it evident that the contributed fuel is enriched to some degree. If it is enriched to the same degree (90%) as fuel used in the U. S.'s MTR-type reactors, each reactor would require about 8 lbs of fuel—thus, about 33 could be built. No reactors could be built with the contributed uranium if it were enriched to only the 1.5–2% of the PWR.

International Conference

Planning for the 1955 conference would be implemented by an advisory committee. Britain, France, Canada, and the U. S. were first named to the committee; later, the seven powers sponsoring the UN resolution suggested that the Soviet Union, Brazil, and India be added to the group. This apparently follows the U. S. idea that the committee should be representative of "knowledge of atomic energy development and . . . geographic location."

The U. S. recommended that the conference should discuss world power requirements, deficits in conventional fuels, nuclear power economics, health and safety, nuclear technology, research reactors, and medical, biological and industrial applications of radioactivity.

While final plans still have to be made by the advisory committee, it is understood that the conference will be open only to official representatives of participating nations. Unsponsored individuals probably will not be able to attend.

U. S. Program

Lodge said that the U. S. is continuing bilateral talks with several nations aimed at setting up research reactors abroad with U. S. materials and advice.

Pointing out that the proposed international agency cannot come into full operation immediately, Lodge listed programs the U. S. will carry out in 1955. He said these "activities will be coordinated with the international agency's own program and may later be undertaken by the agency itself." Included are:

1. A reactor training school will teach 30 or 40 scientists or engineers from overseas the theory and application of power reactors. As bilateral agreements are completed, classified material will be included. Argonne National Laboratory probably will play an important part in this program.

Reactor Fuel Loadings

Name	*Enrichment (%)*	*U metal (tons)*	*Power (kw, heat)*
NATURAL URANIUM			
Graphite moderated			
GLEEP	0.7	12*	100
X-10	0.7	35	3,800
BNL	0.7	60	28,000
BEPO	0.7	28–40	4,000
CP-2	0.7	10†	2
Hanford	0.7	?	$\sim 10^5$
CP-1	0.7	6‡	0.1
Sellafield	0.7	?	?
Belgian	0.7	30	3,500
D_2O moderated			
CP-3	0.7	3	300
NRX	0.7	10	40,000
ZEEP	0.7	?	0.30
ZOE	0.7	0?§	5
P-2	0.7	3.75?	1,500
JEEP	0.7	~2.5	300
ENRICHED URANIUM			
Graphite moderated			
NAA proposal	?	0?¶	160
D_2O moderated			
CP-3′	?	9 lb	300
CP-5	?	2.6 lb	1,000
Water boilers			
LOPO	14	9 lb	<0.001
HYPO	14	14 lb	6
SUPO	88	1.8 lb	45
N. C. St.	90	2.2 lb	10
NAA	90	1.5 lb	0.001
MTR type			
LITR	90	7 lb	2,000
BSF	90	7 lb	100
MTR	90	9 lb	30,000
ORR	90	6 lb	5,000
Pa. State	90	8 lb	100
U. of Mich.	90	8 lb	1,000
PWR	1.5–2%	15–20	264,000

* Plus 21 tons U_3O_8. † Plus 42 tons U_3O_8. ‡ Plus 40 tons U_3O_8. § About 3.5 tons U_3O_8. ¶ About 7 lbs U_3O_8.

(Great Britain, in a similar action, is opening its School of Reactor Technology at Harwell to foreign students next June.)

2. A one or two year course in industrial medicine at universities. Medical treatment required in industries concerned with atomic energy will be taught.

3. Courses in industrial hygiene will teach the techniques needed for maintaining healthful conditions in industries dealing with atomic energy.

4. Instruction to be given at Brookhaven National Laboratory will cover radiological physics and use of radiation instruments.

5. Use of atomic energy in medicine and biology will be taught in one to two year courses with five to ten persons per course at Argonne Cancer Hospital, Brookhaven, and the Oak Ridge Institute of Nuclear Studies. Also, as many as 150 visitors will be invited to visit cancer research facilities.

6. Special four-week courses for foreign technicians will expand the present limited program for training in radioisotope tracer techniques.

To supply other nations with information on atomic energy, the U. S. has assembled ten libraries, will assemble more if needed. These provide over 200,000 index cards each and in addition contain reports, journals, and abstracts for the last seven years. Additions will be made to these libraries as material is published.

Australia and Japan have already received libraries of unclassified material from AEC, although not as part of the plan announced to the UN.

Argonne Talks to Utility, But Not About Selling Power

Reports that Argonne National Laboratory is discussing sale of power generated in its planned Experimental Boiling Water Reactor to Commonwealth Edison Co. have been branded a "pipe dream" by an ANL spokesman.

EBWR's 5,000-kw output just about matches the laboratory's own power requirements, and Commonwealth has been brought in on the problem of how this supply could be tied in with existing service to the laboratory.

Actually, no final plans have been made for using EBWR power. It's doubtful that Argonne could enter into direct negotiations for sale of power to a private utility; the Atomic Energy Law of 1954 grants preference to public

Washington Report

Democratic election victories and Presidential appointments are changing the top-level governmental lineup in atomic energy. Both the Atomic Energy Commission and the Joint Congressional Committee on Atomic Energy are affected.

Following his rapid-fire appointment of two scientists—Libby and von Neumann—to AEC, President Eisenhower nominated one of the three "businessman" Commissioners—Joseph Campbell—as Controller General of the United States. Campbell's AEC term, which started in 1953 and was to end next June, automatically ends when his appointment is approved by the Senate.

One snag may delay Senate confirmation: Campbell has sided with AEC chairman Strauss in approving the controversial Dixon-Yates power proposal, thus provoking Democratic ire. Because of the Dixon-Yates controversy, Senate action of Campbell, along with that on Libby and von Neumann, has been deferred until after January 1.

When the 84th Congress convenes in January, Senator Clinton P. Anderson, Democrat from New Mexico, will be chairman of the Joint Committee. He succeeds W. Sterling Cole, Republican of New York. Democratic control of the new Congress, coupled with an agreement made when Cole was named that the chairmanship would alternate between House and Senate gives Anderson the job.

Another change in the Joint Committee lineup was brought on by election of Senator Edwin C. Johnson as governor of Colorado. To replace him, the Democrats have named Albert Gore, Senator from Tennessee.

At least two other Joint Committee seats will change in January as the 10-to-8 majority swings to the Democrats.

•

AEC's "reactor of the year" scheme, wherein AEC would split the cost with industry on a nuclear power plant that industry would build and own, is moving slowly. First, AEC lawyers say the plan has to be revamped because of the "no subsidy" section (Sec. 169) in the new law. No AEC money can be used in the "construction or operation of facilities licensed under section 103 or 104 except under contract or other arrangements entered into pursuant to section 31 ('research assistance')." AEC hopes some form of research "arrangement" can be worked out.

A second stumbling block is the interest of industry in the plan. A number of companies were reported to be preparing proposals. But several private utilities were apparently scared off because of the bad publicity they felt the Dixon-Yates contract had given the utility industry. They were afraid of using government money on an industry-owned project.

•

An AEC staff paper on the **proposed "gray" areas of classification** is expected to be acted on by the Commission before the end of the year. Meanwhile, specifications for *L*-clearance, which would provide access to gray area information, have been approved by AEC. Although most companies deeply immersed in the atomic energy business will undoubtedly continue to require *Q*-clearances for many of their personnel, it is expected that *L*-clearance will be of particular benefit to new companies in the field.

•

AEC is wrestling with the difficult and important problem of setting a **"fair price" for special nuclear material** to be delivered to AEC by potential operators of nuclear power plants. A suggested figure is now going the rounds within AEC. It is expected that the final price will lie somewhere between the weapons value of plutonium and its value as reactor fuel.

•

A special committee is now being cleared by AEC to study problems relating to the insuring of nuclear facilities.

Sidelights

Boron-10: how much is available? Officially, Atomic Energy Commission says it has enough boron-10 to meet both domestic and international demands for this isotope used in neutron counters. But AEC hedges by adding "if the quantities are not unreasonable." All of AEC's supply stems from a single batch bought several years ago; no hint of further production has been made. But Britain is setting up a boron-10 production facility.

•

Hanford made "radiation control area." Posting of signs recently was first step in making the entire Hanford production area a radiation control area. Object is to limit travel on some roads to lessen burden of decontaminating them.

•

Belgians form nuclear syndicate. Chief shareholders of a syndicate formed in Brussels are electrical, metallurgical, and chemical companies, together with the Union Miniere du Haut-Katanga and the Societe Generale de Belgique. Aimed at doing groundwork for Belgian nuclear power, the planning group will train engineers, assemble information, and hunt for financing.

•

Complete geochemical lab. A new $500,000 building at Columbia University's Lamont Geological Observatory, Palisades, N. Y., now houses equipment for age determinations and natural radioactivity measurements.

•

Japan plans nuclear power plant; progress tour first step. Japan's governmental Board of Industrial Technology is planning to send 15 scientists to the U. S. and Europe to study nuclear research progress. The government has decided to start construction of an experimental power reactor within five years.

•

Award contract for MTR irradiation facility. The building to house the gamma irradiation facility in the Materials Testing Reactor area (NU, Nov. '54, p. 124) will be built by Arrington Construction Co., Idaho Falls. Arrington won AEC contract with low bid of $67,870, also bid low ($32,350) for partitioning MTR building and installing two monorail cranes.

•

Washington State College wants research reactor. With a reported $200,000 available, State College of Washington (Pullman, Wash.) is interested in building a swimming-pool reactor. Harold Dodgen is directing State's nuclear project.

•

France plans an atomic submarine. Included in France's shipbuilding program for next year is a nuclear-propulsion submarine.

•

U. S., Japan, meet on effects and uses of radiation. Representatives of the AEC joined the Japan Science Council for five days in Tokyo last month to exchange information on radiation measurement, effect, decontamination, and research use.

•

West Germany plans civilian atomic program. Chancellor Adenauer has informed Allied authorities that the Bonn government wants to set up a research program, including a 10-Mw reactor, within two years.

•

Kaiser nuclear power study approved. AEC has approved the 18th nuclear power study under its industrial participation program. Kaiser Engineers Div. of Henry J. Kaiser Co. will study power-reactor feasibility.

•

Fermi gets first AEC special award. Following a recommendation of its General Advisory Committee, AEC has awarded $25,000 to Enrico Fermi for "especially meritorious contributions" to atomic energy development. Award is authorized by patent section of new Atomic Energy Law.

and cooperative power groups when surplus power is disposed of by Atomic Energy Commission installations. Although AEC regulations implementing this provision have not been written, the preference clause would seem to require public announcement and bidding.

Australia Includes Reactor In 5-Year Development Plan

An experimental 10,000-kw reactor power plant will be built near Sydney, Australia. As part of a cooperative program with Great Britain, Australia is embarking on a five-year program aimed at industrial power. More than $12-million will be spent.

Howard Beale, Australian Minister of Supply, predicts that nuclear power will be economic within 10 years. Parts of his country, while economically important, are far from the coast and from conventional fuel sources.

The experimental reactor plant will be located as near to Sydney as safety allows and as near a source of sea or fresh water as possible.

Forum Plans Film Series for Use on Television

The Atomic Industrial Forum will start production of a motion picture series on "Atomic Energy Today" this month. Arrangements have been made for at least 300 television showings of the 30-minute films during next year.

Three to five industrial applications will be depicted in each of 12 films in the series. Individual company participants will meet the costs of showing their activities. Preference will be given to Forum members in choosing sponsor companies.

Swiss Plan Reactor Aimed at Economic Power

Having arranged to get 10 tons of uranium from Belgium (NU, Oct. '54, p. 76, Nov. '54, p. 120), Switzerland's federal government now is setting up an organization to build an experimental reactor. A decree published last month authorizes the government to subsidize a company to build a reactor and conduct necessary experiments.

While the project is aimed at developing nuclear energy for economic use, lack of reactor design details prevents analysis of how far the project will go. Cost is estimated at $2.7-million.

Born, Bothe, Pauling Win Nobel Prizes

Linus Pauling has been awarded this year's Nobel Prize for chemistry; Max Born and Walther Bothe have won the physics prize.

The Royal Swedish Academy of Science honored Pauling for his studies of protein-molecule structure and for application of his work to "elucidation of the structure of complex substances." Pauling is a professor at California Institute of Technology.

Born, who recently retired from Edinburgh University, Scotland, was cited "for his fundamental research in quantum mechanics, especially for his statistical interpretation of the wave function." Bothe, head of the Institute for Physics of Max Planck Institute for Medical Research, Heidelberg, Germany, was honored "for the coincidence method and his discoveries made with this method."

EDUCATION

Brooklyn Poly adds nuclear option for ChE's. Five courses in nuclear engineering can be used as a minor sequence in Polytechnic Institute of Brooklyn's chemical engineering department. Atomic and nuclear physics, nuclear chemistry, nuclear reactor technology, and chemical processing of fission products are included.

Radioisotope use taught in Cuba. Twenty-four students from Latin American countries will complete the second UNESCO-sponsored course on radioisotope techniques on Dec. 23 at University of Havana. Marcelo Alonso, U. of Havana, Ovidio de Laosa, director of the radioisotope laboratory at Curie Hospital in Havana, and H. D. Bruner of Emory U., Georgia, developed the course.

ORINS elects officers, administers participation and fellowship programs. Oak Ridge Institute of Nuclear Studies has reelected Paul M. Gross president and C. K. Beck vice president.

Applications for participation in the Oak Ridge Research Participation Program are available to university faculty members. This joint ORINS-Oak Ridge National Laboratory program supports research projects for as long as a year. Further information is available from University Relations Division, ORINS, Box 117, Oak Ridge, Tenn.

Atomic Energy Commission fellowships in radiological physics and industrial hygiene are also administered by ORINS; applications for 1955–56 can be obtained from the above office. The two programs support study at universities and AEC installations leading to master's degrees.

RAW MATERIALS

PERU: aids U. S. ore search. R. R. Beard, AEC raw materials division geologist, is in Lima directing a uranium exploration program. United States is carrying out the search under operating agreements with South American countries.

UNITED STATES: adds more processing facilities; starts "uranium derby." Even before expansion contracted four months previously was completed, Anaconda Copper Mining Co. discovered more ore near its Bluewater, N. M., ore processing plant. So Anaconda has contracted with AEC for construction of a further addition to the plant.

Avowed purpose of the "uranium derby" sponsored by *The Army Times* is to aid the government's search for uranium. The publication will provide any war veteran with a Geiger counter for ten days without charge after he tells where he'll search and why. Entrants also have to report results, are offered no prizes. So far, 20 counters are out on loan.

MADAGASCAR: set U, Th ore prices. French AEC purchasing station at Fort Dauphin is currently paying 1,500 francs/kg of uranium metal content, 500 francs/kg of thorium metal content for ores containing at least 8% U. Ores with 4% U are accepted if Th content is at least 40%. The Central French Africa franc is double the value of the French franc.

AUSTRALIA: unwrap ore data to stop bogus uranium promotions. Prospectors and mining companies can now disclose estimated ore reserves, ore grades, and production rates for uranium mines. But most useful data for investors—Bureau of Mineral Resources reports and assays—still cannot be used without specific authorization.

SOUTH AFRICA: estimate 6-month profit of $9.5-million. In first half of this year, recovery of uranium from gold-mine residues provided an estimated profit of $9.5-million. Top profit was earned by West Rand Consolidated: over $2.8-million. Tied for second place were Daggafontein and Western Reefs: $1.75-million each.

NEWSMAKERS

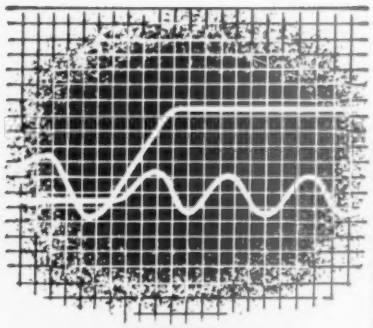
Joseph C. Rengel and **Philip N. Ross,** as manager and assistant manager, will direct the LSR (large ship reactor) project at Westinghouse Electric Corp.'s atomic power division.

E. L. Zebroski, formerly project engineer for the submarine advanced reactor at General Electric's Knolls Atomic Power Laboratory, is now manager of the nuclear engineering section of Stanford Research Institute, Stanford, Calif.

C. L. Comar is now a principal scientist on the medical division staff of Oak Ridge Institute of Nuclear Studies. He has resigned his former post of laboratory director of the University of Tennessee—AEC agricultural research program.

Reassignments in Washington have caused the following changes in the Atomic Energy Commission: **R. W. Cook** is now deputy general manager, and also continues as assistant general manager for manufacturing. **H. S. Traynor** is now assistant general manager directing the divisions or offices of security, organization and personnel, intelligence, information, classification, and source and nuclear materials accountability. **D. F. Musser** is now director of the division of source and nuclear materials accountability. Previously, this division was a branch of the division of production. **R. B. Snapp** is now special assistant to the chairman of AEC. He is succeeded as secretary to the Commission by **W. B. McCool. P. N. Foster** is the new special assistant to the general manager for liaison.

C. D. W. Thornton has been named to head AEC's office of operations analysis, succeeding **D. P. Heron.** Reporting directly to AEC general manager K. D. Nichols, the office provides technical advice on major operational problems not assigned to an operating division or on problems concerning several divisions.



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ABOUT THE INDUSTRY

Nuclear Instrument Market

In 1955–60, annual sales of nuclear instruments should average $40-million. AEC estimates the 5-year market to be (in millions): government—$115; radioisotope users—$55; uranium industry—$15; export trade—$8; power and research reactors—$5. Requirements of AEC, according to R. L. Butenhoff, are: "AEC has over 180,000 radiation instruments [worth] $13-million. This does not include reactor controls and other electronic circuitry which could easily account for another $20-million. The depreciation and turnover of instruments is high, especially for research-type instruments. Requirements for new or improved instruments continually arise as the program develops. There is a growing demand for instruments that will permit automatic control of production operations and greater accuracy and speed in taking measurements. Instruments and equipment for analyzing and handling data are becoming essential to nuclear research."

$369,000 worth of radiation instruments were exported to Western Europe in July, August and September.

Chemical Processing

Chemical processing and recovery of spent nuclear fuels is a phase of the nuclear power plant complex that has not been looked at to any great extent by industry. Some feel there is considerable potential for industrial activity in this area. One company, the Vitro Corporation, has a processing study contract with AEC. Vitro plans to take a hard look at how it might reduce processing costs. The company reports that it will "tackle a specific design approach" to a power reactor presently being considered by industry. Vitro also wants to "map out a concept for a central reprocessing and refueling plant to service utilities and one to serve marine or aircraft propulsion reactors."

AEC Operating Budget Grows

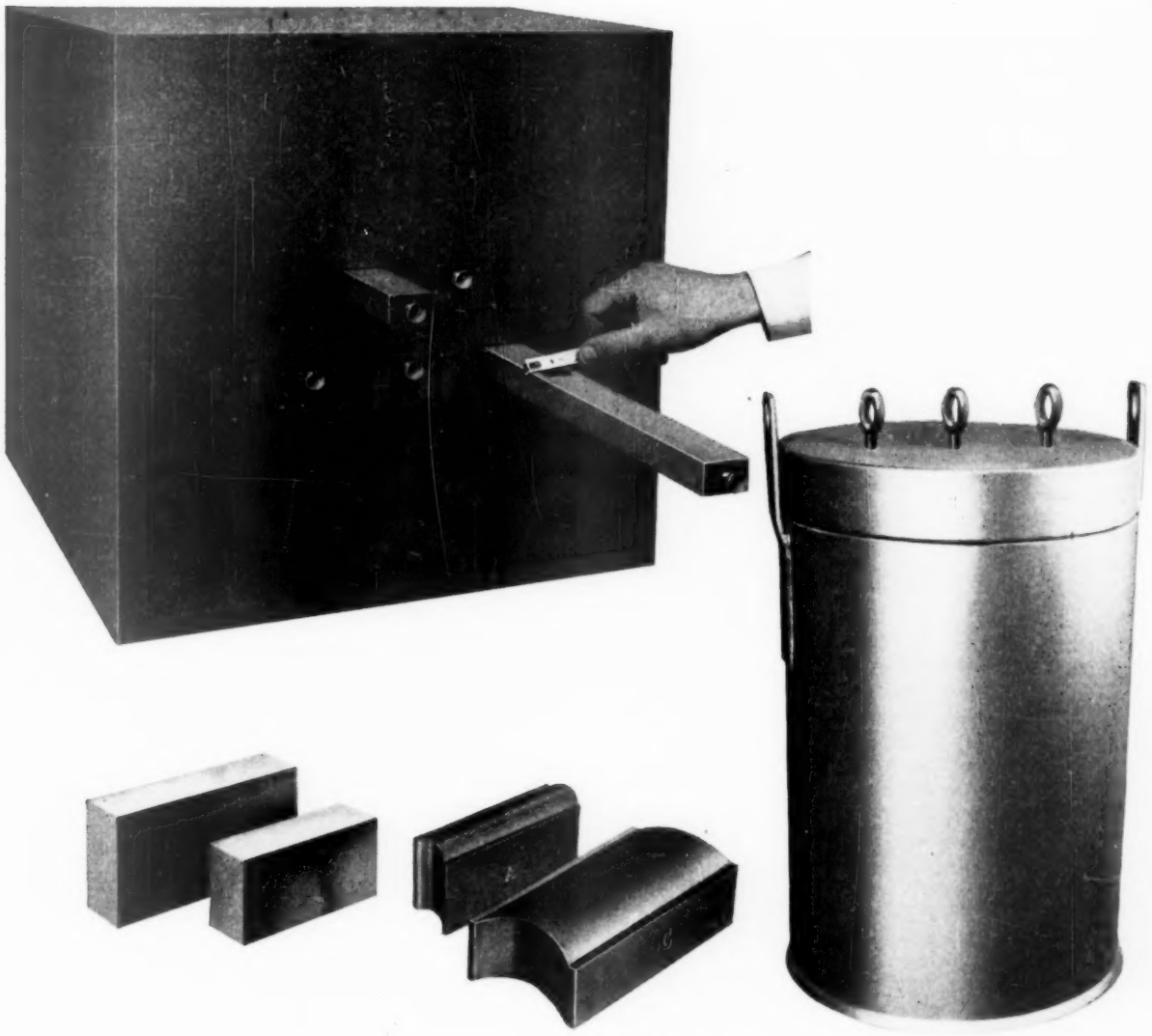
As AEC construction of new plants is completed, more money will go into operating costs. The operating budget is expected to level off at about $1-billion per year. In fiscal '54, AEC spent $232-million on products used in the operation of plants, laboratories, testing facilities, etc.

New Nuclear Activity

A growing trend in the atomic energy field is for major companies to concentrate their nuclear activities in special divisions. Latest to do this is Glenn L. Martin. This company has spent the last year building up a staff under T. F. Nagey, formerly with the National Advisory Committee for Aeronautics. Its principal interest is in designing and building reactor systems, including pressurized-water type. Martin has submitted a bid on the Army power reactor and is now working on a design of one that might be carried in a plane as a portable power source. In addition, the company is interested in selling: propulsion reactors for surface ships up to destroyer size; heat exchangers for liquid metals; control-rod systems, including servomechanisms; fuel elements. Martin is considering setting up, via a cooperative plan, an industrial engineering and service reactor. It might go on a university campus.

Isotope Committee

A useful way to exploit possible radioactivity applications also comes out of Glenn L. Martin. The company has set up an isotope committee with representatives from each phase of the firm's operations—e.g., engineering, quality control, manufacturing, etc. Also on the committee is a nuclear specialist. At committee meetings, problems from the various departments are tossed on the table. If it looks like using radioactivity would be the answer, the company's nuclear laboratory investigates the problem and reports back with recommendations.



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Custom Shielding

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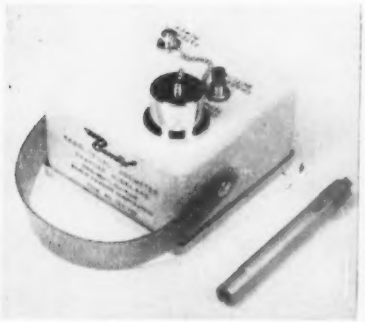
A leaflet on "Lead Shielding" will be mailed to you if you ask for it. Please address nearest Branch.

National Lead Company

New York 6; Atlanta; Baltimore 3; Buffalo (Depew P.O.); Chicago 80; Cincinnati 3; Cleveland 13; Dallas 2; Philadelphia 25; Pittsburgh 12; St. Louis 1; Boston 6 (National Lead Co. of Mass.); *Los Angeles 23* (Morris P. Kirk & Son, Inc.); *Toronto, Canada* (Canada Metal Company, Ltd.).

Want more information? Use post card insert in this issue.

PRODUCTS AND MATERIALS



Ionization Chambers for Health Physics and Civil Defense

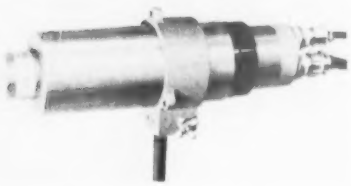
A new line of dosimeters and two new multiple-range dose-rate meters have been announced.

Handy Bendix high-range clip-on pocket dosimeters (left, above) are available in ranges from 0–5 r to 0–1,000 r; for Co^{60} radiations, accuracy is 10% and linearity is 3%. Accuracy is within ±25% for radiation from 50 kev to 3 Mev. Chargers are also available. *Bendix Aviation Corp., 203 W. Third St., Cincinnati 2, Ohio.* (P-1)

Tissue-equivalent ionization chamber (available separately) enables new survey meter (right, above) to measure rep directly. Three ranges, 0–10/100/1,000 mr/hr, and 0–0.1 mr integrated dose are included in this battery-operated instrument. *Radiation Industries Co., Box 232, Brookhaven, N. Y.* (P-2)

New Neher-White ionization chamber on a 50-ft cable permits remote measurement of radiation from 0.01 mr/hr to 100,000 r/hr substantially independent of energy from 75 kev up. *Jordan Electronic Mfg. Co., Inc., 119 E. Union St., Pasadena 1, Cal.* (P-3)

RADIATION DETECTORS AND ACCESSORIES



Two Scintillation Counters

These versatile products can fill many laboratory counting requirements.

Improved scintillation counter (above) may be fitted with any of 12 different hermetically sealed, light-tight crystals. Plateaus are 2%/100 v for 300 v. *National Radiac, Inc., 10 Crawford St., Newark 2, N. J.* (P-4)

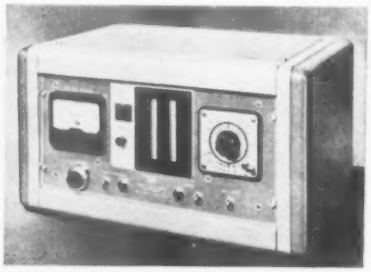
Model SC-2M counter (not illustrated) has adjustable manual sample changer and variable collimation. It uses 1-in.-diameter × 1-in.-high NaI(Tl) crystal; model SCIU is available with interchangeable crystals for α, β, γ, and n counting. *N. Wood Counter Laboratory, 5491 Blackstone Ave., Chicago 15, Ill.* (P-5)

BF_3 Neutron Counter

WL-6307 proportional counter, 12 in. long and 1 in. in diameter, is filled with 55 cm Hg of 96%-enriched $B^{10}F_3$. Sensitivity is 4.5 cps for unit thermal-neutron flux. *Westinghouse Electronic Tube Division, Dept. T-297, Box 284, Elmira, N. Y.* (P-6)

Neutron Monitor

Model 2715 battery-operated monitor uses two enriched BF_3 detectors, one for thermal neutrons, other surrounded by paraffin and cadmium shield for neutrons above 1 ev; it is insensitive to 1-r/hr γ-rays. Neon lamps and earphones provide indication. *Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago, Ill.* (P-7)



Three Scalers

Of these decimal scalers, two utilize decimal counting tubes with direct readout.

Model SG-2A scaler (above) has scale of 1,000, built-in non-overloading amplifier with 1-mv sensitivity, 2-μsec resolving time and stable dual-range high-voltage supply. *Technical Measurement Corp., 140 State St., New Haven, Conn.* (P-8)

Type N530 EKCO automatic scaler and timer presents elapsed time up to 100,000 sec by means of Dekatron tubes, counts to 10^6 with 5-μsec resolution; high-voltage supply and preamplifier are built in. *American Tradair Corp., 405 Lexington Ave., New York 17, N. Y.* (P-9)

Model PN 123/A by M. B. L. E. of Belgium, has 20-μsec resolving time. High-voltage (250–1,800-v) power supply and 0.1-sensitivity preamplifier are built in. *A. A. Beckwith, 50 Vanderbilt Ave., New York 17, N. Y.* (P-10)

RADIOACTIVITY MATERIALS, APPARATUS

Radioisotopes

Some cyclotron- and reactor-produced isotopes are offered in approximately maximum quantity shown: Be^7, 1 mc; Na^{22}, 500 μc; V^{48}, 10 mc; Cr^{51}, 1 mc; Mn^{54}, 100 μc; Fe^{55}, 500 μc; Zn^{65}, 1 mc; Cd^{109}, 100 μc. Other shorter-lived radioisotopes are available, also carrier-free activity, and labeled compounds. *N. V. Philips-Roxane, Isotopes Labora-*

tory, P. C. Hooftstraat 171–177, Amsterdam, The Netherlands. (P-11)

Sardap

Small-angle-radiation-detection-and-presentation system, TU-3A, combines well-collimated source, collimated scintillation detector, and associated electronics for liquid-level control, density control, and radiography. Detects 0.001-in. variation in 1-in. steel plate. *Nuclear Research Corp., Southampton, Penn.* (P-12)

Isotope Scanner

Collimated scintillation-counter housing scans up to 14 × 17 in. area at continuously variable speed. Line space is variable from $\frac{1}{16}$ in. Print relay, in full view of operator, provides up to 4 copies of pattern. Scan frame is 58 in. above floor, permitting 30-in.-high examination table. *Isotope Accessories Co., Box 5458, Philadelphia 43, Penn.* (P-13)

ANALYTICAL INSTRUMENTS

Spectrograph-arc generator. Universal Generator provides continuous arc, intermittent arc, unipolar discharges, and intermittent sparks; variable current is 0.3–1,000 amperes. *Scientific Specialties Corp., Snow and Union Sts., Boston 35, Mass.* (P-14)

Gas-purity analyzer-recorder. Panel-type instruments record, indicate, and control production quantities of gases or laboratory samples. *Gow-Mac Instrument Co., 100 Kings Rd., Madison, N. J.* (P-15)

X-Ray quantometer. Curved crystal permits simultaneous analysis of 8 elements; element percentage is recorded in <2 min. *Applied Research Laboratories, Glendale, Calif.* (P-16)

Dissolved-oxygen analyzer. Model 1A3B combines scrubbing mechanism for removing gases from liquid and analyzer for measuring oxygen in removed gases. *Arnold O. Beckman, Inc., 1020 Mission St., S. Pasadena, Calif.* (P-17)

Aerosol, smoke photometer. By using forward-scattered light, portable unit has observable concentration range of 100–100,000 times. *Phoenix Precision Instrument Co., 3803 N. Fifth St., Philadelphia 40, Pa.* (P-18)

Fractional-distillation apparatus. Heli-Robot low-cost, low-temperature apparatus has semiautomatic controls and fractionating column. *Podbielniak, Inc., 341 E. Ohio St., Chicago 11, Ill.* (P-19)

CIRCUIT COMPONENTS

Resistors, Capacitors

Here are some new resistors and a high-temperature capacitor.

Type L resistors wound on steatite cores and sealed in epoxy resin, perform accurately in the face of extreme humidity, altitude and corrosive influences. Available in a complete line of standard and subminiature sizes. *Resistance Products Co., 714 Race St., Harrisburg, Pa.* (P-20)

Designed for high-frequency applications, resistors are available from 20 ohms to 200 megohms in $\frac{1}{4}$–2 w ratings. *Phaostron Co., 151 Pasadena Ave., S. Pasadena, Calif.* (P-21)

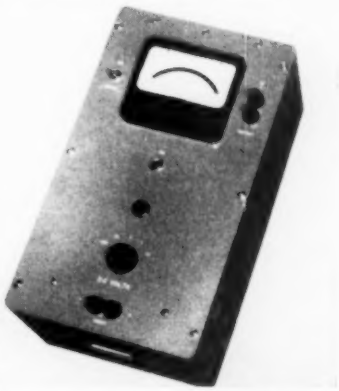
Type HC resistors are ruggedized, hermetically sealed, and available in resistance ranges to 200 megohms, power ratings of $\frac{1}{2}$, 1, and 2 w. Standard tolerance is 1%. *Dale Products, Inc., Columbus, Nebraska.* (P-22)

PR-1 resistor is hermetically sealed, offers temperature coefficient that is independent of resistor value. HT-2 capacitor will operate at 200° C without derating; high insulation resistance (5×10^{14} ohms) means capacitor can hold charge for more than a year. *Balco Research Laboratories, 49–53 Edison Pl., Newark 2, N. J.* (P-23)

Deposited-carbon resistors are available in $\frac{1}{4}$, $\frac{1}{2}$, 1, and 2-watt size, have insulation resistance above 100,000 megohms. *Rockbar Corp., 215 E. 57 St., New York 16, N. Y.* (P-24)

Carbon-film resistors are available in all standard sizes; type A has 5% tolerance, type D, 0.5%. *Arnhold Ceramics, Inc., 1 E. 57 St., New York 22, N. Y.* (P-25)

ELECTRONIC APPARATUS



Vacuum-Tube Voltmeters

Models covering the range from 1 mv to 100 kv are new this month.

The 213-A millivoltmeter (top, above) has zero-center movement and full-scale deflection of 1 mv. Internal noise and drift are below 10 μv d-c. Gain-of-1,000 d-c amplifier channel is included. *Industrial Control Co., Wyandanch, N. Y.* (P-26)

Ruggedized miniature a-c vacuum tube voltmeter (above, bottom) takes no more panel space than standard $3\frac{1}{2}$-in. meter. Single scale sensitivities

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from 10 mv to 300 v are available, and multiple-scale operation is easily effected. *Trio Laboratories, P. O. Box 143, Wantagh, N. Y.* (P-27)

Model LVM-5 uses null method to achieve 0.05% resolution and linearity in 0–100-v range; serves as comparison bridge, electronic millimicroammeter. *Computer Co. of America, 149 Church St., New York 7, N. Y.* (P-28)

Model 124 precision d-c voltmeter measures 0–500 v by null method using built-in standard cell. *Furst Electronics, 3322 W. Lawrence Ave., Chicago 25, Ill.* (P-29)

Model VM-82 has 11 d-c ranges from 50 mv to 500 v; input resistance is 50 megohms. Probe with half-wave germanium-diode rectifier permits use from 10 kc to 200 Mc. *Scientific Specialties Corp., Snow and Union Sts., Brighton 35, Mass.* (P-30)

Model J-1002 high-voltage voltmeter employs vacuum capacitor divider to measure voltages from 100 to 100,000 v. Frequency response is from 50 cps to 20 Mc. *Jennings Radio Mfg. Corp., 970 McLaughlin Ave., P. O. Box 1278, San Jose 8, Calif.* (P-31)

Oscillators and Amplifiers

Three oscillators from two manufacturers head this listing.

Transistor oscillator, type 1307-A, (above) produces 400 and 1,000 cycles accurate to 3% at 2 v into 600 ohms. It uses 3 mercury A batteries and 1 *pnp* junction transistor. Type 1304-B beat-frequency, 1-w, 600-ohm, audio oscillator is latest version of a classic instrument. Frequency range is 20 cycles to 40 kc. *General Radio Co., 275 Mass. Ave., Cambridge 39, Massachusetts.* (P-32)

Model 301 Utility Oscillator covers range from 12 cycles to 1 Mc in 6 ranges. Output is 10 v into 600 ohms. Model 202 a-c (20 cycles up to 2 Mc) voltmeter-amplifier has full-scale ranges from 1 mv to 300 v. Accuracy is under 5%. *Shasta Division, Beckman Instruments, Inc., P. O. Box 296—Station A, Richmond, Cal.* (P-33)

Four-channel carrier amplifier has 0–3,000-cycle frequency response. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, California.* (P-34)

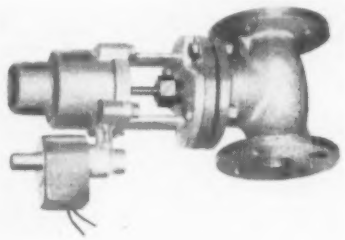
Type 2HLA-3 d-c indicating amplifier has gain of 10^4, 0–20-cycle bandwidth; accurate zero-center mirror-scale provides for use as indicator. *Dolecam Corp., Soldiers Field Rd., Boston 35, Mass.* (P-35)

PUMPS, VALVES, AND SEALS

Fast-Response Vacuum Gages

Hastings model GV-7 (above, top) vacuum gage uses directly heated noble-metal thermocouples and nickel-plated gage tubes to avoid corrosion, outgassing, and contamination when measuring pressures from 1 to 0.001 mm Hg. Gage-tube calibration is unaffected by exposure to atmospheric pressure or changes in ambient temperature. *Hastings Instrument Co., Inc., Warwick, Va.* (P-36)

Alphatron model 517 (bottom) gage uses a sealed radium unit as source of alpha particles to ionize gas molecules that collect on a plate to produce pressure-measuring current. Gage measures pressures from 1,000 to 0.0001 mm Hg. *Naresco Equipment Corp., 160 Charlemont St., Newton Highlands 61, Mass.* (P-37)



Solenoid-Controlled Valves

New line of cylinder-operated solenoid-controlled valves made of various materials are suitable for handling corrosive gases and liquids. They have full-area ports, can be mounted in any position, can be either normally open or closed, and are available with standard, watertight, or explosion-proof solenoid enclosures. *Automatic Switch Co., 391 Lakeside Ave., Orange, N. J.* (P-38)

Double-Seal Ball Valve

Electrolytic corrosion that causes many valve failures can be prevented by using a new double-seal ball valve made of same material as the piping system. Available in many metals and sizes from $\frac{1}{4}$ to 2 in., the ball-type valve is designed to permit nonturbulent flow and positive shut-off at 600 lb/in² even under extreme abrasive and corrosive conditions. *Jamesbury Corp., 15 Union St., Worcester 8, Mass.* (P-39)

PUMPS, VALVES IN BRIEF

Hermetic seals. Hexseal series-9000 high-pressure single-unit seals keep moisture, dust, and combustible vapors from leaking through rotary switches and around panel-mounted shafts. Present models fit $\frac{1}{4}$-in. shafts and a $\frac{3}{8}$-in. threaded bushing. *Automatic & Precision Mfg. Co., 252 Hawthorne Ave., Yonkers 5, N. Y.* (P-40)

Tube fitting. Swagelok flare connector is designed for switching from flare fittings to Swagelok leakproof torque-free tube fittings; available from $\frac{1}{8}$ to 1 in. *Crawford Fitting Co., 884 E. 140th St., Cleveland 10, O.* (P-41)

Hydraulic piston seal. BW series S-11052 pressure-responsive dual piston ring seal is available in standard sizes from 1 to 4 in. o.d. Said to be tough,

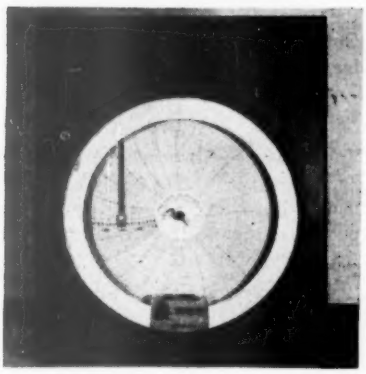
extremely inert, and corrosion-resistant, seal is usable from −100 to 300° F up to 5,000 lb/in². *W. S. Shamban & Co., 11617 W. Jefferson Blvd., Culver City, Calif.* (P-42)

O-rings. Buna-N fuel- and oil-resistant compounds are being used in a new series of industrial O-rings. Standard sizes range from ¼ to 16 in. o.d. *Stillman Rubber Co., 5811 Marilyn Ave., Culver City, Calif.* (P-43)

Manual shut-off valves. New 900 series valves are rated 0–3,000 psi and can be used in either hydraulic or pneumatic lines. *Circle Seal Precision Valves, 2181 E. Foothill Blvd., Pasadena 8, Calif.* (P-44)

Metallic O-rings. Gold-plated metallic O-rings are being developed for sealing gases and corrosive liquids under extremes of temperature and pressure. *United Aircraft Products, Inc., Dayton, Ohio.* (P-45)

FLOW METERS AND REGULATORS



Electronic Flow Meter

Indicating, recording, continuous-type mechanical integrator, or combinations of these models measure gas or liquid flow. Metallic-bellow, rupture-proof differential pressure transmitters are available for 20–750 in. water with standard static 1,500-lb/in² operating pressure; higher ratings can be supplied. Transmitter-recorder system employs differential transformers, null-balance a-c system, electronic amplifier, and continuously operating 6-counter integrator. *The Hays Corp., Michigan City, Ind.* (P-46)

Variable-Area Flow Meter

Fluid-flow meter combines in-line installation of differential orifice with linear signal of variable-area meter. Sizes for ½–12 in. pipe lines cover 0.2–

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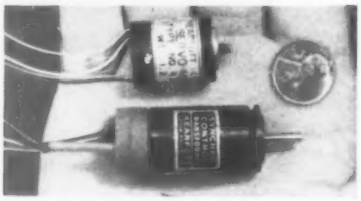
2,000 gal/min of liquid, 10–60,000 lb/hr of steam, or 1–6,000 ft³/min of gas. *Devicengineering Co., 1701 Walnut St., Philadelphia 3, Pa.* (P-47)

By-Pass Flow Regulator

Type 1801 flow regulators, for systems requiring constant flow rate less than pump output, provide 0.3–12.0 gal/min for ⅜- and ½-in. pipes at 3,000 lb/in² operating pressure. Regulation is ±10% of regulator's calibrated flow rate with differential pressures across regulator of 75–3,000 lb/in². *Waterman Engineering Co., 725 Custer Ave., Evanston, Ill.* (P-48)

SERVO COMPONENTS



Synchronous Motors

Two series of synchronous motors are available.

Servo motors and synchros, ¾-in. diameter and having straight-through bore and integral stator-housing (above, top), have following characteristics: 6,500-rpm no-load speed, 0.1-oz-in. stall torque, 1.5-watt power input/phase, 18-volt input/phase, and 1.2-oz weight; highly damped model has 4,000-rpm no-load speed. *Kearfott Co., 1378 Main Ave., Clifton, N. J.* (P-49)

Motors for magnetic tape drives provide synchronous speeds of 300–1,800 rpm (above, bottom), with standard capstans, of 1⅞, 3¾, 7½, 15, and 30 in./sec. Extended or double-ended shafts and variations in mounting details, direction of rotation, line voltage, and frequency are available. *Technical Development Corp., 4060 Ince Blvd., Culver City, Calif.* (P-50)

Data repeater. Dual-synchro and helipot-type repeaters have ±0.03-deg static accuracy, 25-cps bandwidth, velocity constant in excess of 13,000, 3,000-oz-in./deg torque constant, and 300-deg/sec max. slewing speed. *Midwestern Geophysical Laboratory, 3401 S. Harvard, Tulsa, Okla.* (P-51)

Miniature clutch. Available as clutch and clutch brake, $^{63}/_{64}$-in. max. diameter unit transmitting 8 oz-in. torque with 65-ma control current. *Magtrol, Inc., 533 S. Niagara St., Tonawanda, N. Y.* (P-52)

Miniature clutches and brakes. Single clutch, double clutch, and clutch brake have 6-msec response time, max., with telephone-type relay; units are designed for 16 oz-in. max. torque and 1,000-rpm intermittent duty. *Ford Instrument Co., 31-10 Thomson Ave., Long Island City 1, N. Y.* (P-53)

Servo amplifiers. Types MAT-1, 2, 3, and 4 amplifiers handle 2, 4, 6, and 9 watt servomotors, respectively, with 115-volt, 400-cycle supply and double that with 230-volt, 400-cycle supply. Output is sinusoidal, amplitude variable, and phase reversible. *United Transformer Co., 150 Varick St., New York 3, N. Y.* (P-54)

Variable-speed transmissions. New Zero-Max 10, 15, and 20 lb-in. torque models have double output shafts, input and output shafts on same side, and shafts opposite from standard unit. *Revco, Inc., 2 E. Franklin Ave., Minneapolis 4, Minn.* (P-55)

Multipole synchro element. Inductosyn serves as shaft-position data transmitter or receiver; 3-in.-diameter device has maximum errors of 5 sec of arc; 108 poles provide 54 synchronous points per revolution. *Farrand Optical Co., Inc., Bronx Blvd. and E. 238th St., New York 70, N. Y.* (P-56)

Helipot. Redesigned miniaturized type AJ offers 0.01% resolution with 0.5% linearity although only 1½ in. long by ⅜ in. diameter. Available in linear versions from 25 to 100,000 ohms, 2w; also nonlinear windings. *Helipot Corp., 916 Meridian Ave., S. Pasadena, Cal.* (P-57)

PRODUCTION EQUIPMENT

Small motors. Two new motors are available. Type SC-5 is rated at 1 hp at 12,000 rpm, has speed regulation of

6% for loads of ¾–1 hp. Motor features 110-lb-in. starting torque. Type SC-23 is governed at 7,100 rpm to 1%, within load variations of 30%. Motor rating is ⅛ hp at 27 v, 6 amp. *Dalmotor Co., 1356 Clay St., Santa Clara, Cal.* (P-58)

Synchronous motors. Variety of motors is available: ratings of 20–700 hp with 1.0 power factor, ratings of 20–600 hp with 0.8 power factor. Exciters are directly connected, take 125 v. Armature temperature rise is 40° C, field temperature rise is 50 or 60° C. *Columbia Electric Mfg. Co., Cleveland 14, Ohio.* (P-59)

Steam generator. Cyclotherm model C1400 is 40-hp package steam generator. Unit operates on gas, oil, or gas and oil combinations. It requires no stack. *U. S. Radiator Corp., Oswego, N. Y.* (P-60)

Induction heater. High-frequency model 5000 has all aluminum capacitor that discharges completely. *Radio Frequency Co., 44 Park St., Medfield, Massachusetts.* (P-61)

Dielectric heater. Model 5000 has double shielded cabinets that reduce radiation below FCC requirements. This portable unit has 5-kw output. *Resdel Engineering Corp., 2351 Riverside Dr., Los Angeles 39, Cal.* (P-62)

Selenium rectifier. Model 6-750T rectifier has 22-step control, from 0–6 v d-c, with ripple of 5%. Unit converts 230–460 v, 3-phase, 60 cycle a-c, includes 4½-in. ammeter and voltmeter. *Crown Chemical and Engineering Co., 4722 Worth St., Los Angeles 63, California.* (P-63)

Vacuum coater. Features of vacuum coater are built-in photometer to measure coating thickness, and rapid pump-down time. Bell jar is made of aluminum. *American Instrument Co., Inc., Silver Spring, Md.* (P-64)

Automatic motor starter. Time delay condulet OFC restarts motors automatically, with adjustable time delay of 2, 4 or 6 sec. Device is explosion-proof and dust-tight. *Crouse-Hinds Co., Wolf and Seventh North Sts., Syracuse, N. Y.* (P-65)

Resistance soldering unit. Model 23 is said to eliminate overheating or burning parts. Adjustable heat-controller (25–1,000 w) and timer are provided. *Vermaline Products Co., P. O. Box 222, Hawthorne, N. J.* (P-66)

Surfacing electrode. Deposits from

new

PORTABLE RADIATION *RECORDING* MONITOR

MODEL PRAM-5

Completely Battery Operated

Esterline Angus Records Radiation 100 hours unattended (12"/hr chart speed)

Housed in Splash-proof Easily Decontaminated OUTDOOR cabinet

Gamma Range 0.1 mr/hr to 100 r/hr
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80 kev up

MODEL PRAM-5

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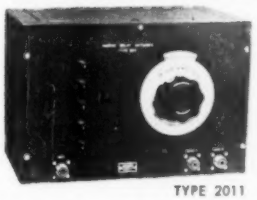
PASADENA 1, CALIFORNIA

INSTRUMENTS FOR

CONTINUOUSLY VARIABLE TIME DELAY

PASSIVE NETWORK

TYPE 2011 and 2012



TYPE 2011

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HS-1 hard-surfacing electrode (a Cr-Mn-Ni alloy) workharden to 48-50 Rockwell C, are applied with a-c or d-c welders. *All-State Welding Alloys Co., Inc., 249–55 Ferris Ave., White Plains, N. Y.* (P-67)

CONTROLLERS, RECORDERS

Graphical Recorder

Model 54-A graphical-numerical recorder uses cash-register tape; achieves large scale record with accuracy through multiple traverses of tape. Numerical printing of traverse identification suppliments line graph. Chart drive is time synchronized or servo driven. Unit measures 9 × 6 × 7 in. *L and O Research and Development Corp., 134 N. Wayne Ave., Wayne, Pa.* (P-68)

pH Controller

Free-Vane *p*H controller with variety of electrical control actions is available. Instrument has jeweled movement, 7-in. mirror scale, dust-proof case. Electrical actions: 2 position; 2 position with normal zone; 2 position with proportional input; and 3 position control. *The Bristol Co., Waterbury 20, Connecticut.* (P-69)

Graphic Recorder

Model 100 recorder has input resistance of ½ megohm, full scale sensitivity of 100 mv. Pen response speed is 1-in./s, accuracy is 1%, reproducibility is ½%. Chart speeds of 1–4 in./m are available. Recorder has front panel zero control. Overall dimensions of model are 10 × 8½ × 6 in. *Hazatrol Corp., 215 Market St., San Francisco, Cal.* (P-70)

Mechanical Integrator

Integrator mechanically computes metered volumes of gases from orifice meter charts. The counter setback operates from main setback post, so range settings are almost infinite in number. When machine is calibrated for one make of charts, it is calibrated for all makes that machine will handle. *Rockwell Manuf. Co., 400 N. Lexington Ave., Pittsburgh 8, Pa.* (P-71)

INDUSTRY NOTES

▶**Anton Electronics Laboratories, Inc.,** Brooklyn, N. Y., has appointed **Joseph P. Della-Corta** director of engineering. Anton manufactures nuclear and electronic equipment.

▶**Kaighin and Hughes, Inc.,** Toledo, Ohio, has organized an industrial waste division that **Edmund B. Besselievre** will manage. Complete engineering and construction services in waste problems are offered by the firm.

▶**John C. Whiddett Co.,** Bala-Cynwyd, Pa., offers complete survey, design and fabrication services on automatic control systems. Policy of making free recommendations on specific control requirements has been instituted.

▶**Nuclear Consultants, Inc.,** is the new name of **Nuclear Research and Development, Inc.,** St. Louis, Mo. Newly formed instrument division will be known as **NRD Instrument Co.** Nuclear Research and Development, Inc. recently separated its consulting and instrument sales activities.

LITERATURE AVAILABLE

Radiation shielding. Catalog 53 describes complete line of radiation shielding equipment. 96 p. *Ray Proof Corp., 513 W. 54th St., New York 19, N. Y.* (L-1)

Prospecting counters. Catalog shows line of Geiger counters for prospecting. 4 p. *Electronics, Inc., Fifth and Noble Sts., Philadelphia 23, Pa.* (L-2)

Rectifiers. Bulletin HDR 854 describes rectifiers rated up to 500 kw. *Perkin Engineering Corp., 345 Kansas St., El Segundo, Cal.* (L-3)

Steam-cleaning compound. Technical data sheet 35 describes heavy-duty detergent for steam cleaning. *John B. Moore Corp., P. O. Box 3, Nutley 10, N. J.* (L-4)

Stepping relays. Bulletin P-84 gives characteristics of stepping relays. 12 p. *Guardian Electric Manuf. Co., 1621 W. Walnut St., Chicago 12, Ill.* (L-5)

Electronic parts. Catalog lists line of radio, tv, and electronic products. 256 p. *The Radio Shack Corp., 167 Washington St., Boston, Mass.* (L-6)

Refractories. Booklets on Gunchrome-M and "Guide for Refractory Selection" are available. *Basic Refractories, Inc., 845 Hanna Bldg., Cleveland 14, Ohio.* (L-7)

Plug-in units. Bulletin 81554 presents variety of plug-in components. 32 p. *Eeco Production Co., 827 S. Vermont Ave., Los Angeles 5, Cal.* (L-8)

Pressure-control problem. Bulletin V-4001 presents the solution of a problem related to a blowdown tunnel. 4 p.

CDC Control Services, Inc., 400 S. Warminster Rd., Hatboro, Pa. (L-9)

Mercury relays. Line of heavy duty enclosed relays is presented by catalog. *Ebert Electronics Corp., Queens Village 28, N. Y.* (L-10)

Surface finish. Booklet explains optical surface testing. 10 p. *William J. Hacker and Co., Inc., 82 Beaver St., New York 5, N. Y.* (L-11)

Electrical ceramics. Bulletin 549 illustrates internal insulators for electron tubes. 4 p. *American Lava Corp., Chattanooga 5, Tenn.* (L-12)

Tungsten. Brochure NP-243 is devoted to manufacture, properties and uses of tungsten. 18 p. *Sylvania Electric Products Inc., 1740 Broadway, New York 19, N. Y.* (L-13)

Gas purifiers. Booklet shows equipment for catalytic purification, hydrogenation and oxidation of gases. 6 p. *Baker and Co., Inc., 113 Astor St., Newark 5, N. J.* (L-14)

Industrial lubricants. Leaflet gives service recommendations for industrial lubricants. 4 p. *Gredag, Inc., Niagara Falls, N. Y.* (L-15)

Controlled-volume pumps. Bulletin 1253 describes characteristics and uses of controlled-volume pumps. 22 p. *Milton Roy Co., Station Y, 1300 E. Mermaid Lane, Phila. 18, Pa.* (L-16)

Steam-turbine history. Booklet 03R-8145 traces turbine development. 22 p. *Allis-Chalmers Mfg. Co., 1316 S. 70th St., Milwaukee, Wis.* (L-17)

Electronic equipment. General catalog lists 25,000 items of electronic equipment. 308 p. *Allied Radio Corp., 100 N. Western Ave., Chicago 80, Ill.* (L-18)

Diffusion pumps. Catalog gives data on diffusion pump line. *Naresco Equipment Corp., 160 Charlemont St., Newton Highlands 61, Mass.* (L-19)

Toroidal inductors. Bulletin TL2-P4 characterizes precision-wound inductors. *Lenkurt Electric Sales Co., 1114 County Rd., San Carlos, Cal.* (L-20)

Printed connectors. Leaflet describes HHB series EC printed-circuit connectors. *H. H. Buggie, Inc., 726 Stanton St., Toledo 4, Ohio.* (L-21)

Recording balance. Bulletin 103 characterizes device for recording small forces with respect to time. 4 p. *Sharples Corp. Research Laboratories, 424 W. 4th St., Bridgeport, Pa.* (L-22)

EKCO Electronic scaling equipment

AUTOMATIC SCALER TYPE N530. This new Type N530 Automatic Scaler times a pre-determined count or counts for a pre-determined time, it can also be manually operated. It incorporates a stabilised high voltage supply for polarising a Geiger-Muller Probe or Scintillation Counter, an input amplifier and a pulse height discriminator.
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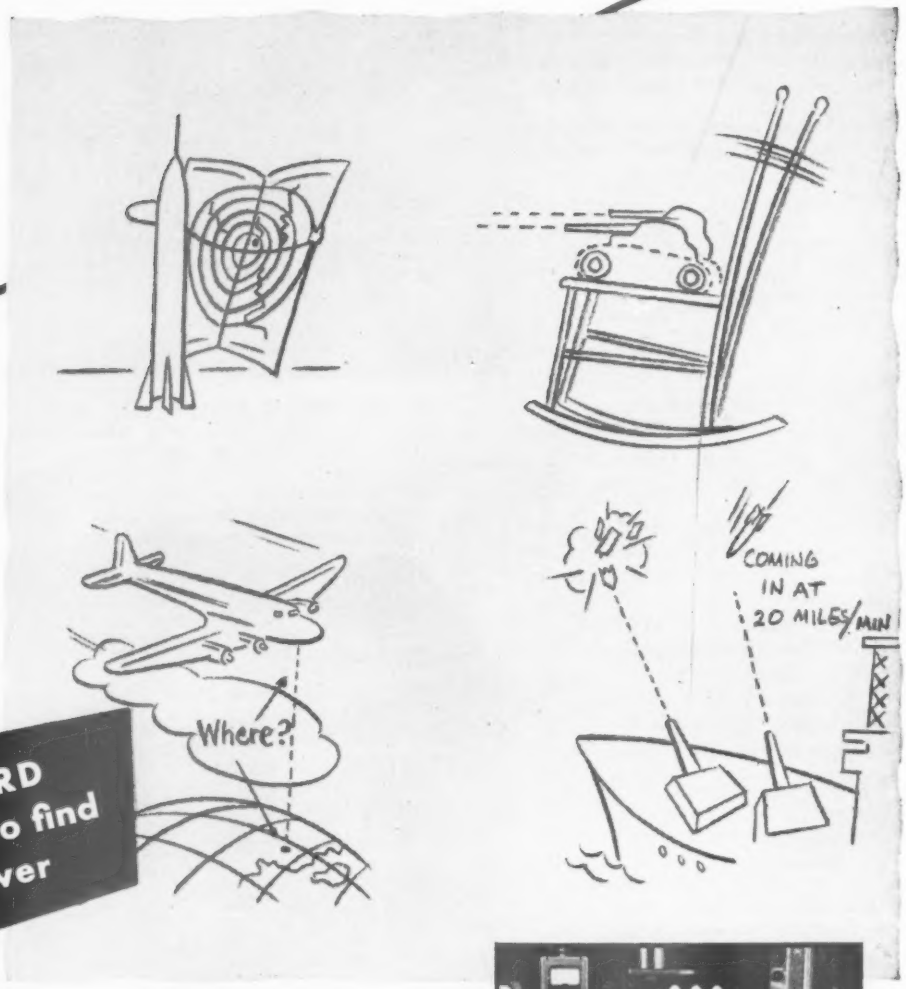

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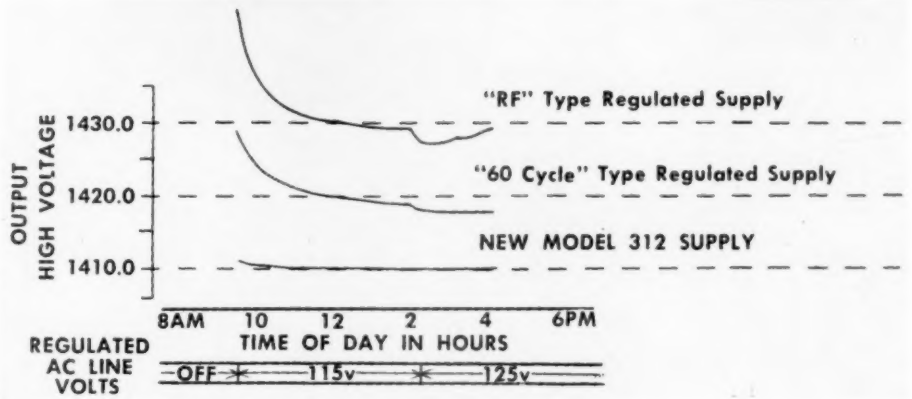

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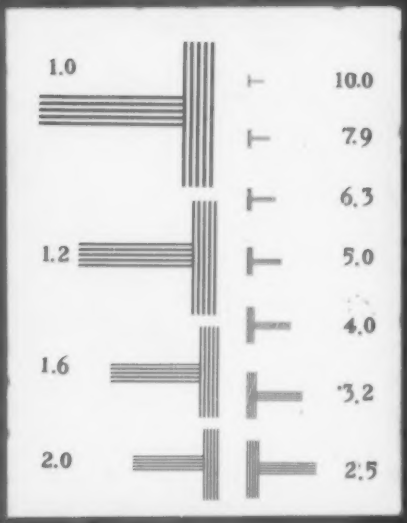

100 MILLIMETERS

INSTRUCTIONS Resolution is expressed in terms of the lines per millimeter recorded by a particular film under specified conditions. Numerals in chart indicate the number of lines per millimeter in adjacent "T-shaped" groupings.

In microfilming, it is necessary to determine the reduction ratio and multiply the number of lines in the chart by this value to find the number of lines recorded by the film. As an aid in determining the reduction ratio, the line above is 100 millimeters in length. Measuring this line in the film image and dividing the length into 100 gives the reduction ratio. Example: the line is 20 mm. long in the film image, and $100/20 = 5$.

Examine "T-shaped" line groupings in the film with microscope, and note the number adjacent to finest lines recorded sharply and distinctly. Multiply this number by the reduction factor to obtain resolving power in lines per millimeter. Example: 7.9 group of lines is clearly recorded while lines in the 10.0 group are not distinctly separated. Reduction ratio is 5, and $7.9 \times 5 = 39.5$ lines per millimeter recorded satisfactorily. $10.0 \times 5 = 50$ lines per millimeter which are not recorded satisfactorily. Under the particular conditions, maximum resolution is between 39.5 and 50 lines per millimeter.

Resolution, as measured on the film, is a test of the entire photographic system, including lens, exposure, processing, and other factors. These rarely utilize maximum resolution of the film. Vibrations during exposure, lack of critical focus, and exposures yielding very dense negatives are to be avoided.